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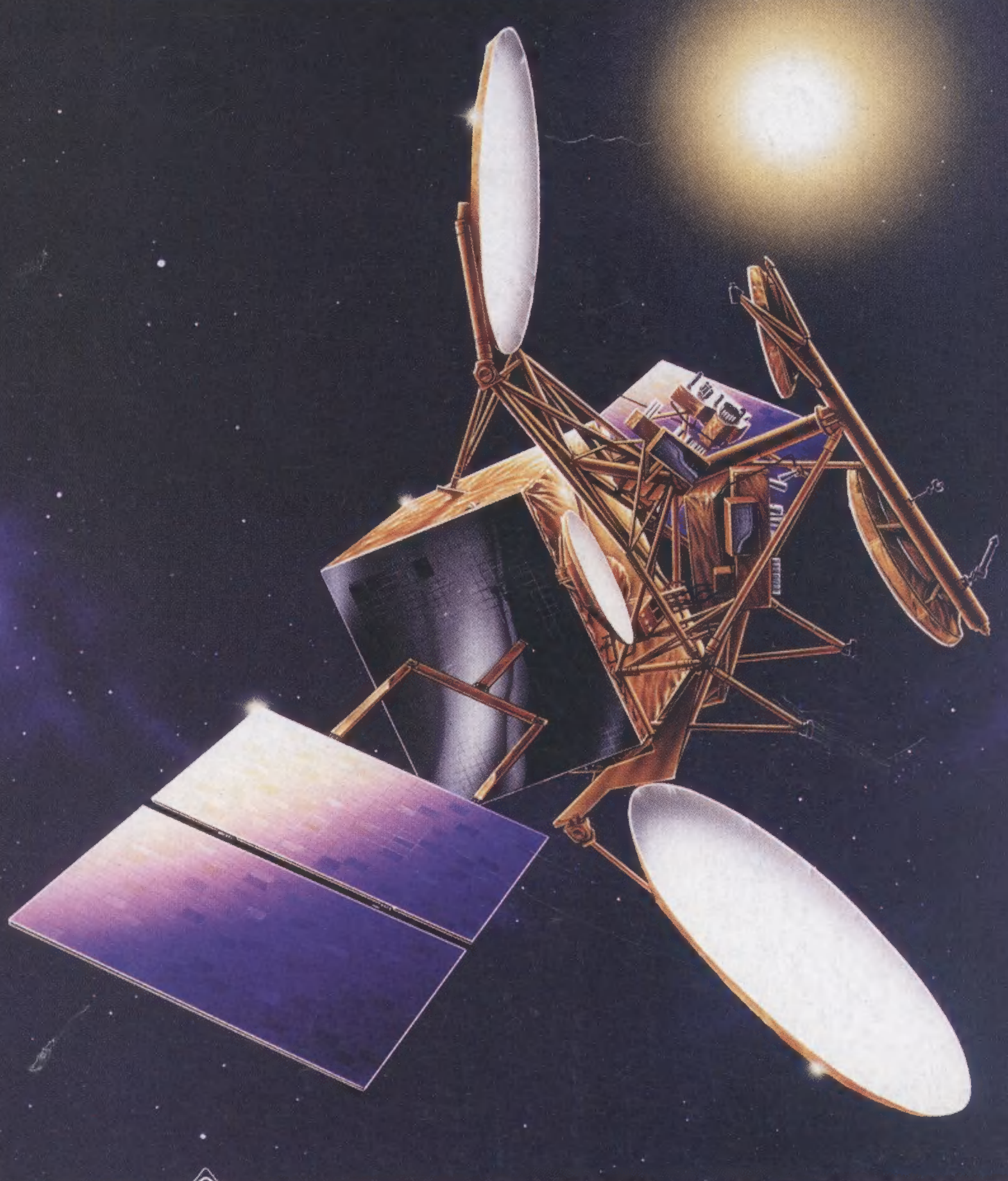
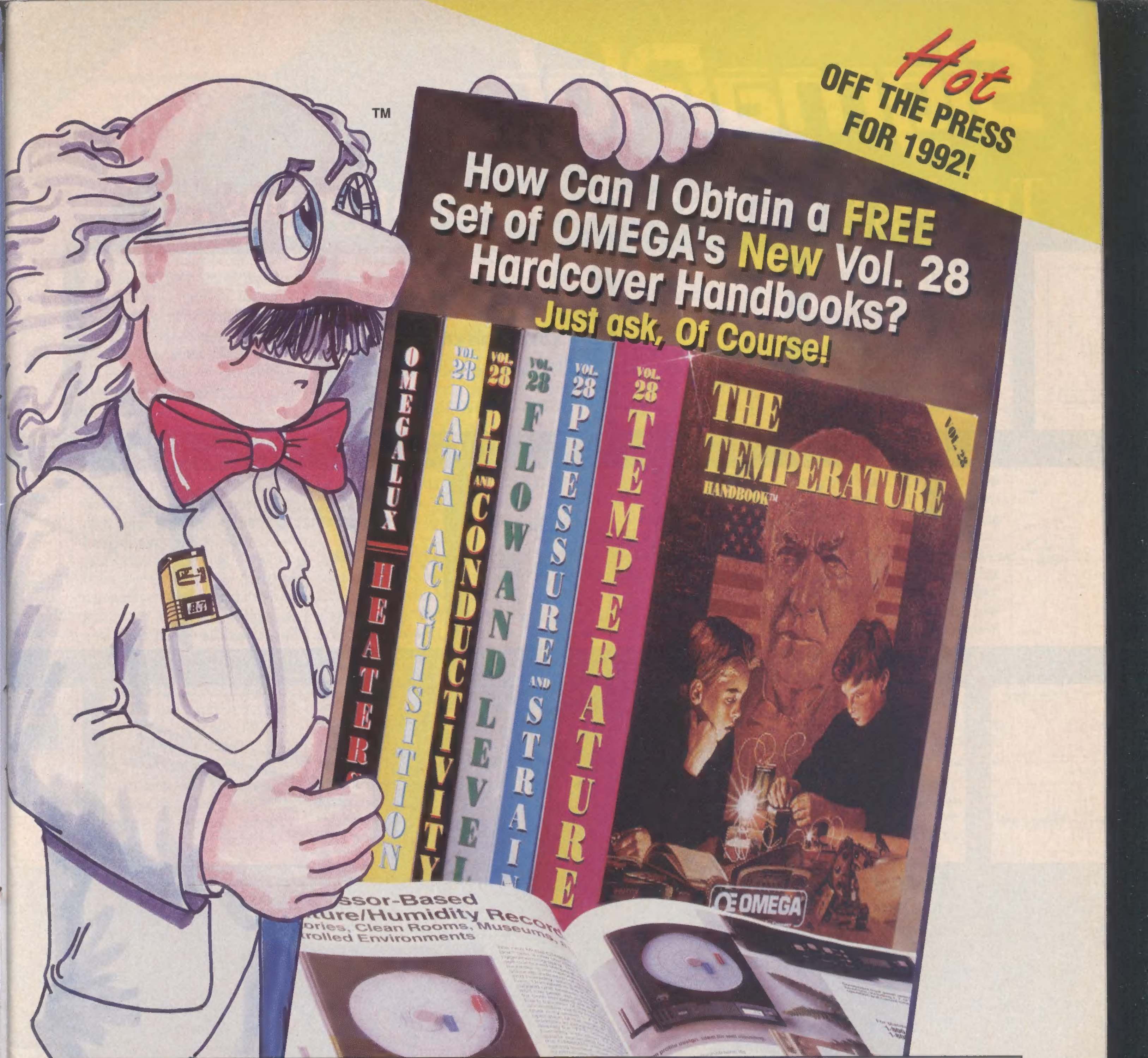
A special preview report



FEBRUARY 1992 THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.



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Newslog

DEC 12. IBM Corp. said it had produced a transistor three times as fast as any predecessor for use in high-performance, low-power computers. Its maximum unity-gain cutoff frequency of 20 GHz stems from the horizontal—rather than vertical—conduction of electricity across the transistor.

DEC 12. The **Federal Communications Commission,** Washington, D.C., adopted new rules to reduce international phone-call rates and open foreign telecommunications markets to competition. From now on, large U.S. long-distance companies must allow aspiring competitors in other countries to lease U.S. international lines at bulk rates and resell them to individual customers—but only if that country allows similar arrangements for U.S. companies. The FCC also approved a plan submitted last year by AT&T Co. and MCI Communications Corp., Washington, D.C., to prevent any long-distance company from switching customers to its services without proper consent.

DEC 17. Intel Corp., Santa Clara, Calif., and **Unisys Corp.,** Blue Bell, Pa., said they had signed an agreement under which Unisys, the third largest U.S. computer maker, will standardize its open-system computers on Intel's X86 line of microprocessors. The companies said they would greatly increase collaboration on defining technical requirements for future Intel microprocessors and would jointly support areas of software development that affect Intel chips.

DEC 17. AT&T Co. said it had closed down the service that gave the company its last name—its 104-year-old telegraph service—because of competition from better and less expensive telecommunications, like electronic data processing and facsimile machines.

DEC 18. IBM Corp. and **Siemens AG,** Munich, said they had built the first production prototype of a 64-Mb dynamic-RAM chip. Production of the chip, which can store 3000 pages of text, is scheduled for 1995.

DEC 18. China said that its first nuclear power plant, built by **China National Nuclear Corp.,** had begun trial operation in Zhejiang. The startup of the 300-MW pressurized-water reactor was delayed for two years by construction problems. Full operation is to begin in June.

DEC 18. The **French Government** announced that it would form a high-technology electronics and nuclear-energy conglomerate—**Thomson CEA Industries**—by combining **Thomson Consumer Electronics** and Thomson's semiconductor activities with the civilian activities of the state-owned **Commissariat à l'Energie Atomique (CEA).** Analysts said the move would mean that R&D funds in electronics would come from the new company's profitable energy arm, not directly from the Government.

DEC 18. General Motors Corp., Detroit, Mich., said it would close 21 of its 125 assembly and parts-making plants in North America and eliminate more than 70 000 jobs, or nearly 18 percent of its employees there, over the next four years. GM said attrition and early retirement could account for many cuts, which it hoped would save US $5 billion by 1995.

DEC 19. A U. S. District judge in San Jose, Calif., dismissed allegations by **Advanced Micro Devices Inc.,** Sunnyvale, Calif., that it had been denied the right to make the 386 microprocessor chip because of secret scheming by **Intel Corp.,** Santa Clara, Calif., in violation of a 1982 cooperative agreement between the two. The judge ruled that the four-year statute of limitations for antitrust actions had run its course before Advanced Micro filed its suit last August. Advanced Micro still has several other claims pending against Intel.

DEC 19. Computer scientist **Misha Mahowald** of the California Institute of Technology, Pasadena, and neuroscientist **Rodney Douglas** of Oxford University, England, said they have collaborated to produce a tiny electronic device—a silicon neuron—that mimics the behavior of a human brain cell. Like a human nerve cell, the device sends electrical signals that can fade or grow stronger.

DEC 26. IBM Corp. said it had agreed to allow **Hitachi Ltd.,** Tokyo, to resell IBM-made notebook computers in Japan under the Hitachi name. IBM said Hitachi would buy at least 2000 computers a month, beginning in April. The machines will resemble the IBM PS/55 notebook, which is configured to operate in both English and Japanese.

DEC 31. The **Federal Aviation Administration,** Washington, D.C., said it had selected **Harris Corp.,** Melbourne, Fla., to produce a $1.7 billion air traffic control system to be installed nationwide over the next 14 years. The equipment links air traffic controllers to each other by telephone and to pilots by radio.

JAN 2. United Telecommunications Inc., Kansas City, Mo., said it would become the sole owner of **U S Sprint** by buying the remaining 19.9 percent from **GTE Corp.,** Stamford, Conn., for $530 million. The purchase caps United Telecom's takeover of the third largest U.S. long-distance carrier, created through the merger of United Telecom's and GTE's long-distance units in 1986.

JAN 6. Market researcher **Dataquest Inc.,** San Jose, Calif., said **Intel Corp.,** Santa Clara, Calif., passed **Motorola Inc.,** Schaumburg, Ill., to become the largest U.S. manufacturer of semiconductors in 1991. Analysts attribute Intel's rise in large part to the near monopoly it has had on the supply of 386 and 486 microprocessors.

JAN 6. LSI Logic Corp., San Francisco, said it would drop out of **Sematech Inc.,** the Austin, Texas, semiconductor consortium, citing disagreements with the group's agenda and its own financial situation. The move comes as Sematech is seeking Government approval to continue its $200 million program—half provided by the Department of Defense and half by member companies—for another five years after its charter expires in October.

JAN 6. The National Aeronautics and Space Administration said it will eliminate 5000 space shuttle jobs over five years, so it can fund a lunar base and a flight to Mars. The cuts—to be achieved through attrition and layoffs—would leave about 20 000 shuttle jobs nationwide.

JAN 9. Officials at Israel's leading technology institute, **Technion** in Haifa, said they had purchased two supercomputers from a British manufacturer, **Meiko Scientific Ltd.** of Bristol, England, for $1.2 million. The machines are at the lower end of the supercomputer speed scale, but are the first to be sold for export without tight restrictions on their use, such as those required for machines sold by U.S. and Japanese companies.

Preview:
FEB 3–MAR 3. The **1992 World Administrative Radio Conference** is to be held in Torremolinos, Spain, to set treaty-level agreements on issues affecting international radio regulations, including spectrum allocations [see pp. 20–33].

COORDINATOR: Sally Cahur

FEBRUARY 1992 Volume 29 Number 2

IEEE SPECTRUM

SPECTRAL LINES

By DONALD CHRISTIANSEN

Converting military contractors into civilian businesses may fail because a commercial venture requires management to take greater risks than defense companies are used to. Skeptics say a bulldozer is needed—to clear away the old business, or at least the old management.

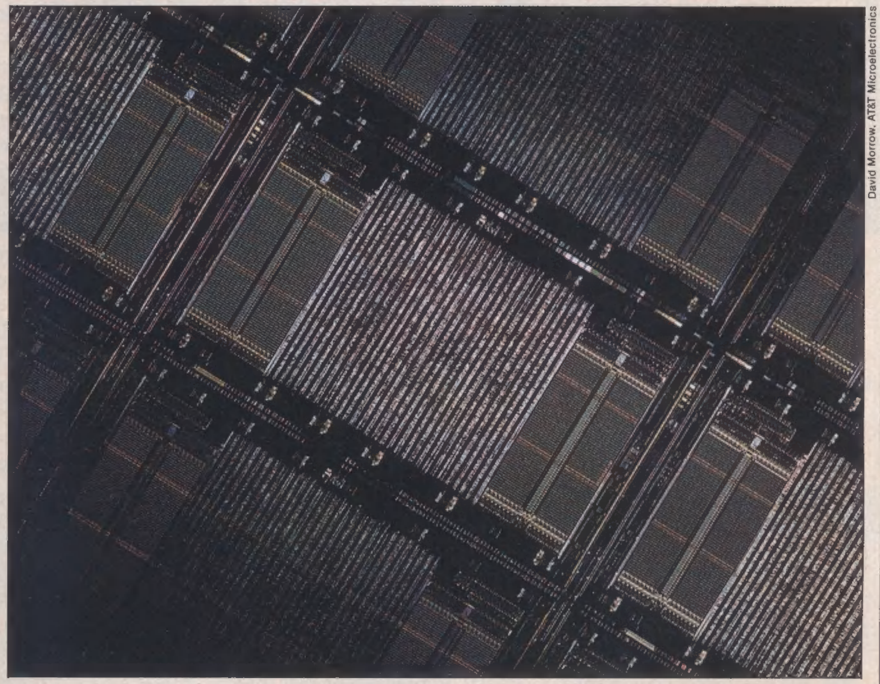
SPECIAL REPORT

By EDWARD E. REINHART, ROBERT M. TAYLOR, ANN O. HEYWARD, and JOEL MILLER

Hughes Aircraft Co.

Now in session, what may be the final World Administrative Radio Conference will allocate spectrum to many types of telecommunication services brought about by major new technologies. Existing telecommunication satellites, such as Hughes Aircraft Co.'s Intelsat VI-F5 (above) beam their transmissions at frequencies allocated to the fixed satellite service.

APPLICATION/SOLID STATE



David Morrow, AT&T Microelectronics

By COLIN M. MAUNDER and RODHAM E. TULLOSS

Loaded digital logic circuit boards can be readily tested thanks to IC makers' acceptance of a standard approach to implementing boundary-scan testing on ICs. Speeding the test process is the development of chips to handle the test, such as those on this boundary-scan master die. Each chip can serve as an intelligent interface between a unit under test and a tester.

APPLICATION/INSTRUMENTATION

By THOMAS A. DYE and ERIK TEOSE

New color and display techniques for digital storage oscilloscopes allow for more meaningful views, as well as complex statistical measurements. For example, the color-graded display in the photograph shows intensity variation on the crossing of an eye pattern signal.

Test & Measurement Group, Tektronix Inc.

COMMUNICATIONS/R&D

42 Switching to photonics

By H. SCOTT HINTON

Switching based on the interaction between photons and electrons promises high capacity and connectivity to telecommunications switching offices of the near future. Hardware like this AT&T Bell Laboratories 16-channel-in, 32-channel-out photonic switch is starting to appear, and other projects are under way around the world.


Lauren Brill

CAREERS/PROFILE

46 Charles R. Trimble

By TEKLA S. PERRY

The Global Positioning Satellite (GPS) may be the world's newest free resource—and Charles Trimble is capitalizing on it. The 10 000 GPS receivers he shipped during the Persian Gulf War were just the start as Trimble seeks military and civilian applications.

PERSPECTIVE/POWER

49 Hawaii boils

By GLENN ZORPETTE

Although once thought relatively benign in environmental terms, a series of proposed geothermal plants in Hawaii has drawn fire from environmentalists and others.

Cover: Poised in space in this artist's rendering is the Advanced Communications Technology Satellite (ACTS), which the National Aeronautic and Space Administration has scheduled to start 20/30-GHz multipurpose communications in 1993. See p. 32
Credit: GE Astro Space

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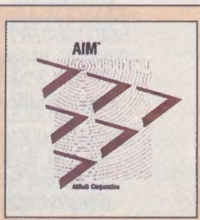
Software reviews

A neural-network–based tool

by Mark Shewhart

AIM is a machine learning tool that combines neural network techniques and statistical modeling to build mathematical models (AIM Networks) of the relationships present in a database of examples. Developed by AbTech Corp., Charlottesville, Va., AIM operates on a wide range of computer systems, including IBM PCs and compatibles, Macintoshes, and Sun workstations running Unix.

AIM Version 1.1. *AbTech Corp. software for building mathematical models of relationships present in a database of examples. The version reviewed requires an IBM PC or compatible, MS-DOS 3.3 or higher, 640K RAM (can use extended memory), a hard drive with at least 2 Mbytes of free space. US $1500. Versions for Apple Macintosh and Unix workstations available.*



Developing an AIM Network begins with the collection of a large database of examples in ASCII format. AIM then automatically splits these examples into two distinct databases: a training data set for generating the mathematical model, and a test data set for evaluating the model. Once generated, the model can be evaluated automatically on the test data set, queried interactively, or encoded as C code. With pull-down menus and dialog boxes, AIM's user interface guides the novice through this process so smoothly that he or she can begin applying the tool immediately, with little reference to the documentation.

AIM is well documented and far easier to learn and use than any other neural network development tool I have evaluated. I learned to use it in less than half an hour and have not needed the documentation since.

AIM's learning/modeling algorithms are relatively fast. My current work with AIM involves large databases of examples (8000 at most) with about 20 independent variables. On a 286 machine with a math coprocessor, AIM required about 8 hours to construct a model of a problem with 8000 examples of data involving 21 variables each. The same problem, when approached with a more conventional neural network algorithm developed at the National Aeronautics and Space Administration and running on a DEC Micro-VAX under Unix, required over 24 processor hours and still did not provide an adequate solution.

AIM's user-friendly interface and ease of application make it far and away the most practical machine learning tool available on the market today. While AIM embodies a very powerful mathematical modeling tool, its true power is the ability of the nonspecialist to apply it; after all, regardless of how much potential a tool has, it is useless if only a few can apply it. *Contact: AbTech Corp., 700 Arris St., Charlottesville, Va., 22901; 804-977-0686; or* **circle 105.**

Mark Shewhart is an artificial-intelligence systems engineer for the Center for Supportability and Technology Insertion at Wright-Patterson Air Force Base in Ohio.

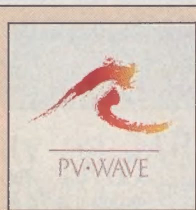
AIM was developed with the support of the Strategic Defense Initiative (SDI) Organization, part of the Department of Defense in Washington, D.C.

Interactive visualization

by John L. Schmalzel

PV-Wave, a workstation-based package for the visualization and analysis of technical data, runs interactively in a Point & Click (P&C) version, allowing rapid access to a full range of file access, analytic, and graphical features. For my evaluation, a Sun SparcStation IPC with 8 Mbytes of memory was used, though 16 Mbytes is recommended. Sample data sets included those provided with the package and sample image files available from an ongoing project.

PV-Wave P&C. *Precision Visuals Inc. Software for data analysis and visualization. The version reviewed, 1.0, is for Sun Microsystems workstations running under Sunview, requiring 16 Mbytes of main memory, 35 Mbytes for program storage, and 50–60 Mbytes for swap space. $4500 for a single floating license. Versions for many other workstations available.*



Installation was simple, and the "Getting Started with..." tutorial was easy to follow and informative. It included step-by-step instructions on how to perform several analysis and display samples, while at the same time giving a good indication of the range of capabilities of PV-Wave P&C.

One striking feature of PV-Wave P&C is the variety of data formats it can import or export; examples are American Standard Code for Information Interchange (ASCII), comma-separated variables (CSV), binary, tagged image file format (TIFF), raster images, and custom. Once in the system, data can easily be viewed in tabular format for editing and verifying the results of selection and subsetting operations. PV-Wave P&C makes it possible to handle very large data sets, in particular to assist in homing in on segments of interest using coarse analysis and visualization.

Data visualization is a key strength of PV-Wave P&C. Available "view windows," which are the windows in which data views are presented, include two-dimensional line or scatter, contour, surface, image, animation, and table. By moving between the display types, a user may try out several ways of visually interpreting data and analysis sets to see which works best. Displays can be monochrome, gray scale, or color (16–256).

On the weak side, PV-Wave P&C's use of mouse keys takes some getting used to for those familiar with click and drag methods of selection. But perhaps the biggest problem I experienced was the slowness of some procedures. This is most likely due to my 8-Mbyte memory limit, yet it works well for other "large" applications. No guidance was given in the manuals for tuning a system for maximum performance. Furthermore, without benchmark data, it is impossible to know how fast things are supposed to be.

What's the bottom line? Considering the array of analysis and visualization features it offers, I think PV-Wave P&C should be seriously considered by workstation users, particularly those performing a variety of WHAT IF analyses on data sets. *Contact: Precision Visuals Inc., 6260 Lookout Rd., Boulder, Colo. 80301; 303-530-9000; fax, 303-530-9329; or* **circle 106.**

John L. Schmalzel, Ph.D., P.E., is an associate professor of EE in the Division of Engineering at the University of Texas at San Antonio; 512-691-5515.

COORDINATOR: Gadi Kaplan

Recent Software

NeWSprint 2.0. Allows users to print files from any computer to any printer on a network. For Sparc-based workstations. US $695. *SunPics, 2550 Garcia Ave., Mountain View, Calif. 94043-1100; 415-960-1300; fax, 415-969-9131; or* **circle 107.**

Eiffel/S. Compiles Eiffel, an object-oriented language, into a source code in C. For MS DOS for 286-, 386-, and 486-based PCs; OS/2; and Atari TOS. $595 (MS DOS), $1200 (OS/2), $185 (Atari TOS). *Interactive Software Engineering Inc., 270 Stroke Rd., Suite 7, Goleta, Calif. 93117; 805-685-1006; fax, 805-685-6869; or* **circle 108.**

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Circle No. 7

Calendar

Meetings, Conferences and Conventions

FEBRUARY

International Conference on Intelligent Control and Instrumentation (Singapore Section); Feb. 18–21; Hilton International, Singapore; R. Devanathan, 200 Jalan Sultan, 11-03 Textile Centre, Singapore 0719; (65) 291 9690; fax, (65) 292 8596.

International Solid State Circuits Conference–ISSCC (Solid State Circuits Council, et al.); Feb. 19–21; San Francisco Hilton Hotel, San Francisco; Diane Suiters, Courtesy Associates Inc., 655 15th St., N.W., Suite 300, Washington, D.C. 20005; 202-347-5900; fax, 202-347-6109.

Applied Power Electronics Conference and Exposition (PEL); Feb. 23–27; Westin Hotel, Boston; Melissa Widerkehr, Courtesy Associates Inc., Suite 300, 655 15th St., N.W., Washington, D.C. 20005; 202-639-4990; fax, 202-347-6109.

Compcon Spring '92 (C); Feb. 24–28; Cathedral Hill Hotel, San Francisco; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

MARCH

First International Fuzzy Systems Conference (COM, IE, NN); March 8–12; Town and Country Hotel, San Diego, Calif.; Nomi Feldman, Meeting Management, 5665 Oberlin Dr., Suite 110, San Diego, Calif. 92121; 619-453-6222.

Fourth International Strategic Software Systems Conference (C, et al.); March 10–11; Von Braun Civic Center, Huntsville, Ala.; University of Alabama at Huntsville, Conference Office, SB/Box 309, Huntsville, Ala. 35899; 205-895-6372 or 800-448-4035; fax, 205-895-6760.

Southcon '92 (Region 3); March 10–12; Orange County Convention/Civic Center, Orlando, Fla.; Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, Calif. 90045; 213-215-3976 or 800-877-2668.

18th Annual Northeast Bioengineering Conference (EMB); March 12–13; University of Rhode Island, Kingston, R.I.; William J. Ohley, Electrical Engineering Department, University of Rhode Island, Kingston, R.I. 02881; 401-792-2505.

IEEE members attend more than 5000 IEEE professional meetings, conferences, and conventions held throughout the world each year. For more information on any meeting in this guide, write or call the listed meeting contact. Information is also available from: Conference Services Department, IEEE Service Center, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855; 908-562-3878; submit conferences for listing to: Ramona Foster, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017; 212-705-7305.

For additional information on hotels, conference centers, and travel services, see the Reader Service Card.

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Calendar

(Continued from p. 8)

Fourth International Conference on Microelectronic Test Structures (ED); March 17–19; Catamaran Resort Hotel, San Diego, Calif.; Michael W. Cresswell, National Institute of Standards and Technology, B360 Technology, Gaithersburg, Md. 20899; 301-975-2072; fax, 301-975-2128.

International Zurich Seminar on Digital Communications (Region 8); March 17–19; Swiss Federal Institute of Technology, ETH-Zentrum, Zurich; Anne Schicker, Box CH-8340, Hinwil, Switzerland; (41+1) 937 2447; fax, (41+1) 938 1557.

Multichip Module Conference (ED); March 17–20; Cocoanut Grove, Santa Cruz, Calif.; Simon Wong, Stanford University, Electrical Engineering Department, CIS 202, Stanford, Calif. 94305; 415-725-3706.

Packaging, Interconnects, Optoelectronics for the Design of Parallel Computers (LEO); March 18–19; Hyatt Regency Woodfield, Schaumburg, Ill.; IEEE/LEOS, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855; 908-562-3894; fax, 908-562-1571.

International Workshop on Intelligent Signal Processing and Communication Systems (C); March 19–20; International Convention Center, Taipei, Taiwan; Naohisa Ohta, NTT Transmission Systems Laboratories, 1-2356, Take Yokosuka-shi 238-03, Japan; (81) 468 59 2072; fax, (81) 468 59 3014.

International Conference on Acoustics, Speech and Signal Processing (SP); March 23–26; San Francisco Marriott, San Francisco; Marcia A. Bush, Xerox PARC, 3333 Coyote Hill Rd., Palo Alto, Calif. 94304; 415-494-4391.

Sixth International Parallel Processing Symposium (C); March 23–26; Beverly Hilton Hotel, Beverly Hills, Calif.; IEEE Computer Society, Conference Department, 1730 Massachusetts Ave., N.W., Washington, D.C. 20036-1903; 202-371-1013; fax, 202-728-0884.

International Reliability Physics Symposium (ED); March 30–April 2; Town and Country Hotel, San Diego, Calif.; Harry Schafft, National Institute of Standards and Technology, Building 225, Room B360, Route 270, Quince Orchard Road, Gaithersburg, Md. 20899; 301-975-2234; fax, 301-948-4081.

APRIL

11th Annual International Phoenix Conference on Computers and Communications (C, COM); April 1–3; Wyndham Paradise Valley Resort, Scottsdale, Ariz.; Joseph Urban, Department of Computer Science and Engineering, College of Engineering and Applied Science, Arizona State University, Tempe, Ariz. 85287-5406; 602-965-2774; fax, 602-965-2751.

Network Operations and Management Symposium (COM); April 6–9; Peabody Hotel, Memphis, Tenn.; Jill Pancio, Pacific Bell, 7620 Convoy Court, San Diego, Calif. 92111; 619-268-6135; fax, 619-292-1509.

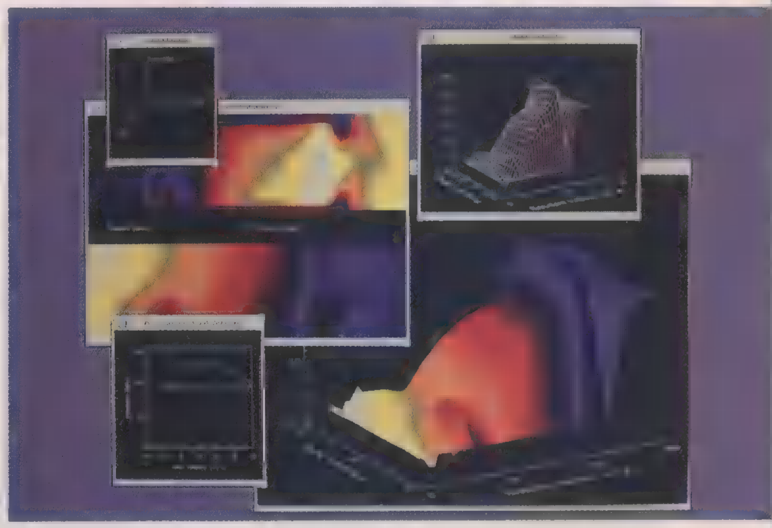
Southeastcon '92 (Region 3, et al.); April 12–15; Wynfrey Hotel, Birmingham, Ala.; Wayne Owen, South Central Bell, 600 N. 19th St., Birmingham, Ala. 35203; 205-321-2299.

Intermag '92 (MAG); April 13–16; Adams Mark Hotel, St. Louis, Mo.; Courtesy Associates, Inc., 655 15th St., N.W., Suite 300, Washington, D.C. 20005; 202-639-5088.

Fourth International Conference on

(Continued on p. 8H)

RAW. WELL DONE.



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Circle No. 33

Calendar

(Continued from p. 8F)

Indium Phosphide and Related Materials (ED); April 21–24; Newport Sheraton, Newport, R.I.; Susan Evans, IEEE/LEOS Executive Office, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-562-3896; fax, 908-562-1571.

Seventh Conference on Semi-Insulating III-V Materials (ED); April 21–24; Krystal Hotel, Ixtapa, Mexico; William Ford, Harris Microwave Semiconductor, 1530 McCarthy Blvd., Milpitas, Calif. 95035; 408-433-2222; fax, 408-432-3268.

MAY

Custom Integrated Circuits Conference–CICC '92 (ED); May 3–6; Westin Copley, Boston; Laura Morihara, Convention Coordinating, 47-344 Waihee Rd., Kaneohe, Oahu, Hawaii 96744; 808-239-4790.

Industrial and Commercial Power Systems Technical Conference (IA, et al.); May 4–7; Sheraton–Station Square Hotel, Pittsburgh; Dave Shipp, Westinghouse Corp., 750 Trumbull Dr., Pittsburgh, Pa. 15205; 412-429-7430.

International Conference on Computer Systems and Software Engineering–Compeuro '92 (C, Region 8, et al.); May 4–7; Netherlands Congress Center, the Hague; P.M. Dewilde, Delft University of Technology, Department of Electrical Engineering, Mekelweg 4, 2628 CD Delft, the Netherlands; (31+15) 7850 89.

International Symposium on Circuits and Systems–ISCAS '92 (CAS); May 10–13; Sheraton Harbor Island Hotel, San Diego, Calif.; Stanley A. White, 433 E. Avenida Cordoba, San Clemente, Calif. 92672; 714-498-5519.

International Conference on Robotics and Automation (RA); May 10–15; Acropolis Convention Center, Nice, France; H. Hayman, Box 3216, Silver Spring, Md. 20918; 407-483-3037; fax, same number.

Microwave Power Tube Conference (ED); May 11–13; Naval Postgraduate School, Monterey, Calif.; Ralph Nadell, Palisades Institute, 201 Varick St., New York, N.Y. 10014; 212-620-3341.

Vehicular Technology Conference (VT, Denver Section); May 11–13; Regency Hyatt Hotel; Jim Schroeder, Department of Engineering, University of Denver, 2390 South York St., Denver, Colo. 80208-0177; 303-871-3519.

Electro '92 (Region 1, et al.); May 12–14; Hynes Convention Center, Boston; Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, Calif. 90045; 213-215-3976; fax, 800-877-2668.

Instrumentation and Measurement Technology Conference (IM, et al.); May 12–14; Meadowlands Hilton Hotel, Secaucus, N.J.; Robert Myers, 3685 Motor Ave., Suite 240, Los Angeles, Calif. 90034; 213-287-1463; fax, 213-287-1851.

Symposium on Worldwide Advances in Communication Networks (COM); May 14–15; George Mason University, Fairfax, Va.; Telecommunications Laboratory, ECE Department, George Mason University, Fairfax, Va. 22030-4444; 703-993-1566.

42nd Electronic Components and Technology Conference (CHMT); May 18–20; Sheraton Harbor Island Hotel, San Diego, Calif.; Peter J. Walsh, Electronic Industries Association, 2001 Pennsylvania Ave., N.W., Washington, D.C. 20006-1903; 202-457-4932.

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Paul K. Weimer
Princeton, N.J

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Calendar

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Indium Phosphide and Related Materials (ED); April 21–24; Newport Sheraton, Newport, R.I.; Susan Evans, IEEE/LEOS Executive Office, 445 Hoes Lane, Box 1331, Piscataway, N.J. 08855-1331; 908-562-3896; fax, 908-562-1571.

Seventh Conference on Semi-Insulating III-V Materials (ED); April 21–24; Krystal Hotel, Ixtapa, Mexico; William Ford, Harris Microwave Semiconductor, 1530 McCarthy Blvd., M 408-433-2222; fax, 4

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Custom Integrate ence–CICC '92 (E Copley, Boston; Lau tion Coordinating, Kaneohe, Oahu, Ha 4790.

Industrial and Com

Forum

Winter of opportunity

The special report on the Gulf War legacy [September] was excellent, especially Glenn Zorpette's "From factory floor to desert war" because it so clearly highlighted the material supply logistics problems. The same kinds of problems are being experienced by the USSR in regard to its worsening food shortages. With sufficient motivation, the Gulf legacy could be extended to answer this growing need.

Often we have been told that food distribution rather than food production has been at the heart of recent shortages. What if the technology, lessons, and determination of the Gulf War supply were applied to this problem? Can the motivation be found? Who would benefit?

The starving would benefit: they would get the food. The newly independent republics would benefit: they would get the tactical know-how. The USSR central government would benefit: it would get the strategic know-how. The U.S. Defense Logistics Agency would benefit: it would practice improving its supply systems. U.S. defense contractors would benefit: they would sell more equipment. U.S. taxpayers would benefit: their dollars would go farther and be spent building up U.S. information capabilities. The world would benefit: it would see the newest swords turned to food distribution also needed in Africa.

The Gulf legacy could grow to be a world legacy. If the IEEE does not initiate this soon, will anyone?

J. E. Drummond
Otis, Ore.

An earlier CMOS patent

The article by Michael J. Riezenman on "Wanlass' CMOS circuit" [May, p. 44] appropriately pointed out Wanlass' significant contributions to the silicon complementary insulated-gate field-effect inverter structures and their application to CMOS logic circuits. The patent cited, however (U.S. 3 356 858, F. M. Wanlass, "Low Stand-by Power Complementary Field Effect Circuitry," filed June 18, 1963, issued Dec. 6, 1967), is not the first to propose the low-power inverter circuit, nor is it the first to describe its use in the CMOS memory element, in which low standby current is essential.

An RCA patent (U.S. 3 191 061, P.K. Weimer, "Insulated-gate Field Effect Devices and Electrical Circuits Employing Such Devices," filed May 31, 1962, issued June 22, 1965) shows in its Fig. 19b the circuit of the basic four-transistor flip-flop memory element used in CMOS. Each branch of the flip-flop is a complementary insulated-gate field-effect inverter consisting of an n-type transistor in series with a p-type transistor.

The sources of the n transistors are connected to ground, the sources of the p transistors are connected to a positive potential source, and the connection between the n and p drains in each branch provides the output of that inverter. For bistable operation, each inverter output is connected to the two input gates of the opposing inverter.

To achieve low-power operation, enhancement-type insulated-gate transistors are used, so that the standby current in each inverter is cut off, regardless of whether its output is high or low. Figure 19a of the RCA patent illustrates a possible layout for the proposed circuit using thin-film transistor (TFT) technology.

Many of the claims to complementary circuits in this patent are generic to various types of complementary insulated-gate transistors, whether fabricated by thin-film techniques or by silicon MOS technology.

I question the value of an article publicizing the contributions of one person to an industrywide development such as CMOS, without proper reference to the contributions of many others. The more conventional method of individual recognition—for example, Wanlass' receipt of the 1991 Solid State Circuit Award—seems far more appropriate.

Paul K. Weimer
Princeton, N.J

From digital to analog

The October 1991 issue featured an article "Video compression makes big gains" [pp. 16-19]. The other engineers used to tell me: "You can't do that!" Well, I was doing it for voice band signals at that time. Video bandwidth compression by large ratios was a further extension in the technique, as disclosed in my patent #3 349 184 and an article in *EDN Magazine* of May 1973. We built a number of pieces of equipment with bandwidth compression/expansion (BC/BE) ratios of 2, 3, 5, and 10, and one that had switchable ratios of 1.5, 2, 2.5, 3, and 4. There was a problem with dynamic range that could have been handled with a compander which was not then available. Even so, performance was quite good.

I did a system study on BC/BE on video signals, but did not have the financial resources to do the development. What I

(Continued on p. 14)

Technically speaking

Capital C

Those of us who work with computers and software have enough trouble using them without involving ourselves in how to capitalize the names of software languages and operating systems. While there is little standardization at present, two basic styles have emerged.

The most common is to capitalize all the letters in computer language names that are acronyms. In fact, most computer languages are acronyms: BASIC (Beginner's All-purpose Symbolic Instruction Code), COBOL (COmmon Business Oriented Language), FORTRAN (FORmula TRANSlation), APL (A Programming Language), JOVIAL (Jules' Own Version of the International Algebraic Language), SNOBOL (StriNg Oriented symBOlic Language), LISP (LISt Processing), ALGOL (ALGOrithmic Language), and so on.

While this style is simple, a word having only capital letters tends to break the flow of the sentence and make the text harder to read. To avoid this, some publications (*IEEE Spectrum* among them) hold that any five-or-more-letter acronym that can be pronounced like an English word should have only the initial letter capitalized, as, for example, Fortran and Basic. But RPG or PL/1 could not be written in this manner. As with any writing style, consistency is the key; FORTRAN and Fortran should not be mixed in the same text, for instance.

Regardless of which of these two styles is used, languages named after people should have only the initial letter capitalized. Here is a partial list of some of the more popular programs and operating systems that are not acronyms, along with their rules of capitalization and brief etymologies.

Ada. In the late 1970s the U.S. Department of Defense was awash in myriad programming languages. The task of auditing programs written in Cobol, Fortran, and other languages was proving very costly to the Government.

To bring some semblance of order, the department commissioned a new standardized language that could be used for embedded systems, and would incorporate features for data abstraction, multitasking, and exception handling.

The resulting language, Ada, was named after Augusta Ada Byron, Countess of Lovelace, and the daughter of Lord Byron, the British poet. She was a close friend and patron of Charles Babbage, a pioneer in the development of calculating machines. Her independent ways made her a modern woman by today's standards, but a rather scandalous figure in her own time. Certainly her curiosity and intelligence were of great help to Babbage, and she is regarded by some as the first computer programmer. Because the language is named after a person, only the first letter is capitalized.

C. The precursor to the C programming language was, appropriately enough, B, which was the offspring of yet another language named BCPL (Basic Combined Programming Language). C was written in the early 1970s by Dennis Ritchie, then a systems programmer at Bell Laboratories and now best known as the co-author of the seminal *The C Programming Language* (Prentice-Hall, Englewood Cliffs, N.J., 1988).

The naming convention ends with C, though; the successor to C is C++. (At one time, according to *The New Hacker's Dictionary*, published last year by MIT Press, Cambridge, Mass., there was some concern about whether the successor to C should be D or P, based on either alphabetical order or the letters in BCPL.) When writing about the C and C++ languages, always capitalize them, and never put them in quotation marks.

FORTH. FORTH is a high-level, extensible language that combines features of both interpreted and compiled languages. Contrary to popular belief, the name is not an acronym. FORTH took shape in the late 1960s, and some of its first uses were for the control of radio telescopes and other astronomical equipment.

The original name was to be FOURTH, for fourth-generation computer language. Unfortunately, the IBM 1130 computer it was developed on could accept only five-letter identifiers, so the name was shortened to FORTH. The consensus is to capitalize it as FORTH, but Forth would be just as proper using the alternative style described above.

Pascal. Pascal was created in 1971 by the Swiss Niklaus Wirth as a tool to teach structured language programming. Named after the famous 17th century mathematician Blaise Pascal, it embodied a simple, structured approach, similar to its namesake's scientific and religious philosophies. Pascal, like Ada, is not all capitals, because it is named after a person.

Modula-2. This is a modular Pascal-based language, also created by Wirth. Only the first letter of Modula-2 is capitalized because it is not an acronym.

UNIX. Contrary to popular belief, UNIX is not an acronym. An interactive time-sharing operating system developed at Bell Laboratories, it started out as a simpler version of a multi-user operating system that was called MULTICS (MULTIplexed Infor-

(Continued on p. 14)

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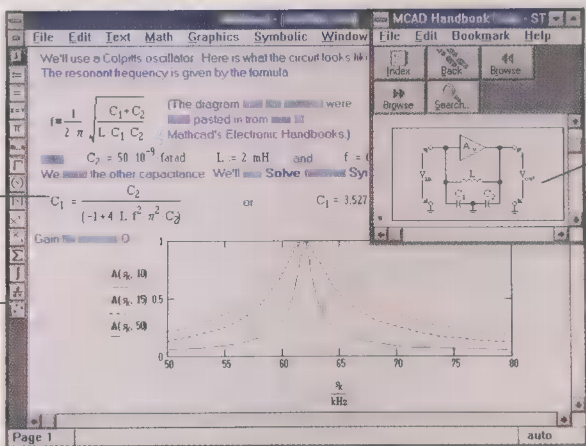

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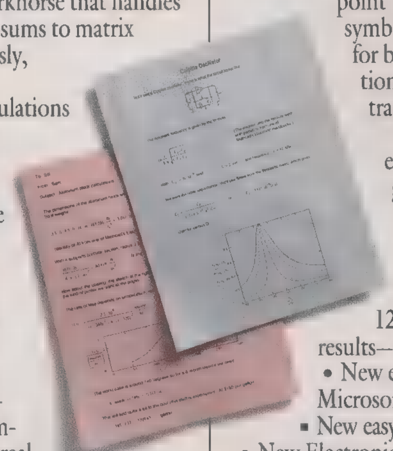

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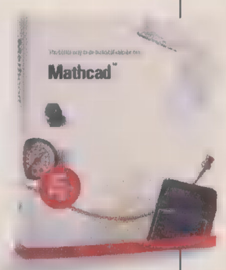

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Circle No. 1

Forum

(Continued from p. 11)

planned was BC/BE for storage or transmission over telephone lines, for example. With analog components available now, it would be noticeably easier than 20 years ago.

Why use analog BC/BE? Present technology of analog-to-digital and digital-to-analog converters makes digital audio work very well, or so I am told. If BC is performed first on any signal, the digital bandwidth can be greatly reduced without significant loss of information (sampling can take place at [redacted] lower rate). The required bandwidth can be greatly reduced without noticeable information loss.

The mathematical basis for my BC/BE is quite simple, but the technology is apparently difficult. I was informed that some people at a highly respected laboratory attempted to duplicate my work, but did not succeed. My thought on the matter was that digital engineers do not understand analog electronics very well.

Harvey Morgan
Winnsboro, Texas

Quick change

The editorial on metric conversion [May, p. 25] prompted me to write. In Australia, metrication was introduced about a decade ago with fair success, because at the outset several major changes were made. All milestones and speed limits were changed virtually overnight countrywide. All sporting activities were redefined in metres/kilometres. All weather information was given in metric terms. For [redacted] time it was illegal to import dual-calibration measuring tools, but this is no longer the case.

Because of existing wide machinery requirements, most fasteners below ½ inch or 12 mm are stocked in Imperial sizes, but above that metric is standard and Imperial is special. In my home workshop I tend to conceive projects in feet and inches but now actually work in millimetres as this is so much more convenient.

If you want to speed up your changeover in the United States, you might use the trick of getting the mass of the people involved by converting sporting activities and auto activities to metric. Then it will only take a couple of generations to complete the changeover.

R. S. Philip Amos
Mosman, Australia

Readers are invited to comment in this department on material previously published in *IEEE Spectrum*; on the policies and operations of the IEEE; and on technical, economic, or social matters of interest to the electrical and electronic engineering profession. Contact: Forum, *IEEE Spectrum*, 345 E. 47th St., New York, N.Y. 10017, U.S.A.; fax, 212-705-7453.

Technically speaking

(Continued from p. 12)

mation and Computing Service).

In its early incarnation, UNIX was a single-user system—hence the *uni* in its name. Author Karla Jennings in *The Devouring Fungus: Tales of the Computer Age* (W.W. Norton, New York, 1990), relates the humorous but likely apocryphal story that the early, scaled-down version of UNIX was missing so many "vital parts" that it was jokingly referred to as Eunics, and only later renamed UNIX.

As [redacted] registered trademark of AT&T Co., UNIX should always be capitalized. However, the development of competing versions by other organizations has led the popular press to use Unix (with only the initial letter capitalized) when discussing all versions of the language collectively. UNIX is also occasionally seen as UN*X to avoid trademark restrictions, while *Spectrum*'s style is to capitalize only the initial letter of trademarks.

XENIX. This operating system for the IBM PC and compatibles is similar to Unix. It is [redacted] registered trademark of Microsoft Corp., and so, like Unix, it should be capitalized, though it is seen in *Spectrum* and elsewhere with only the first letter capitalized.

Catronics?

As engineers, we suppose our profession to be one based on careful observation and study. But it is a little-known fact that the name electronics is itself the result of an ancient misunderstanding.

The word electron derives from the Latin *electrum*, which in turn derives from the Greek *elektron* (Eta Lambda Epsilon Kappa Tau Rho Omicron Nu). It means amber, the fossil, and also an amber-colored, silver-gold alloy. The word appears often in classical Greek texts, and Homer mentions it in his *Odyssey*. It was the first, middle, and last letters of *elektron* that gave its name to Eta Kappa Nu, the international electrical engineering honor society.

Electron took on its modern meaning when ancient Greek philosophers discovered that an amber rod, after being rubbed with wool, would attract small bits of paper. Although we now know static electricity to be the force involved, the Greeks attributed the mysterious properties to the amber rod—hence our use of the words electron and electricity today.

One wonders what name might have evolved had the early Greeks been able to replace the wool and amber rod with [redacted] rubber balloon and a cat.

COORDINATOR: Kevin Self
CONSULTANTS: Anne Eisenberg, Polytechnic University; Everdeen Tree, University of Houston; Edward McCreary, Compaq Computer Corp.


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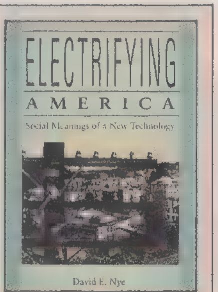
Books

An electrifying story

Ronald Kline

Electrifying America: Social Meanings of a New Technology, 1880–1940. Nye, David E., MIT Press, Cambridge, Mass., 1990, 479 pp., $29.95.



In this splendid book, David Nye, a historian and American Studies scholar at the University of Copenhagen in Denmark, opens a new era in our understanding of electricity in U.S. life.

Unlike most historians, Nye concentrates on the ordinary people who used electricity instead of the inventors, engineers, and businessmen (like Thomas Edison, Charles Steinmetz, and Samuel Insull) who produced and distributed it. Such social history is difficult to do well because of the paucity of written and oral remarks by users, but Nye has overcome these problems to a great degree by analyzing the cultural meanings of electricity as reflected in magazine articles, advertisements, novels, catalogs of world fairs, and many other sources.

He begins by describing how electricity transformed Middletown (Muncie, Ind.), the city made famous by Robert and Helen Lynd in their sociological study of the 1920s. Middletown's street lighting, trolley cars, and factories, homes, and farms underpin the book's organization, as Nye explores the social history of each in turn. The sequence corresponds roughly to the order of electrification in the United States: utilities introduced electricity in crowded cities by lighting the Great White Way, then extended trolley lines out radially to create "streetcar suburbs," which also tied these early suburbanites to the urban center.

Electricity was thus a public, urban experience and was viewed as a luxury good until utilities developed the industrial market before World War I and the home market thereafter. Home economists and builders played key roles in the latter development, while the Federal government's Rural Electrification Administration (1935) sped up dramatically the rate at which farms were connected to central station service.

Nye observes that the adoption of electricity "had profound consequences for the design of the city, the craft of the theater, the structure of the factory, the ambience of the home, the landscapes of art and photography, transportation systems, systems of communication, and forms of security—in short, for the total social construction of reality, including the futures that Americans imagined." Yet he also recognizes that these results were "culturally determined," and that powerful groups like electrical manufacturers, utilities, and the Federal government influenced the kind of electrical system we have today.

Electricity never fulfilled the utopian visions that Americans of all political persuasions held—that it would clean up the cities, decentralize industry, and create a "rururban" paradise. But, as Nye says so

Books

eloquently, these visions were an important part of the social meaning of a new technology. Electricity came packaged in a "familiar blend of technology, ceremony, popular enthusiasm, salesmanship, public relations, private interests, and politics that promoters combined in electrifying America" (p. 391).

My only complaint is that we hear from few ordinary people—how they thought or felt about this new technology. I hope Nye and others follow this extraordinary study with attempts to capture directly the social meanings described here so well.

Ronald Kline (M) is an assistant professor of the history of technology at Cornell University in Ithaca, N.Y. He is the author of the forthcoming Steinmetz: Engineer and Socialist *(Johns Hopkins University Press, Baltimore, Md.).*

COORDINATOR: Glenn Zorpette

Recent books

Application Environment Specification (AES), Revision B. *Open Software Foundation*, Prentice-Hall, Englewood Cliffs, N.J., 1991, 1083 pp., $39.

Iterative Identification and Restoration of Images. *Lagendijk, Reginald L.*, and *Biemond, Jan*, Kluwer Academic, Norwell, Mass., 1991, 208 pp., $67.50.

The M68000 Microprocessor Family: fundamentals of assembly language programming and interface design. *Liu, Yu-cheng*, Prentice-Hall, Englewood Cliffs, N.J., 1991, 449 pp., $52.

Norton Utilities 5.0: an illustrated tutorial. *Evans, Richard*, Windcrest Books, Blue Ridge Summit, Pa., 1991, 343 pp., $26.95.

Intelligent Manufacturing Systems. *Kusiak, Andrew*, Prentice-Hall, Englewood Cliffs, N.J., 1991, 443 pp., $48.

Computational Electronics: semiconductor transport and device simulation. Ed. *Hess, K., et al.*, Kluwer Academic, Norwell, Mass., 1991, 268 pp., $75.

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Computers, Interfaces and Communication Networks. *Collin, Serge*, Prentice-Hall, Englewood Cliffs, N.J., 1991, 109 pp., $25.80.

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Gallium Arsenide Digital Circuits. *Wing, Omar*, Kluwer Academic, Norwell, Mass., 1991, 188 pp., $55.

Basic Communication Skills for Technology. *Rutherford, Andrea J.*, Prentice-Hall, Englewood Cliffs, N.J., 1991, 334 pp., $28.

Spectral lines

FEBRUARY 1992 Volume 29 Number 2

The plowshare problem

Will traditional military contractors like Northrup, McDonnell Douglas, General Dynamics, and Grumman survive the cutbacks in military spending? Continuing force reductions for these companies and others like them sharpen the concern about their viability.

Are they broad based enough, or potentially so, to take up the slack through nonmilitary projects?

John E. Montague, Martin Marietta Corp.'s vice president for corporate development, recently addressed a small group of journalists on the topic. Montague cited differences in corporate culture between government and commercial businesses as among the most serious blocks to successful conversions.

A government contractor is accustomed to risking a reasonably definite sum of money to win (or lose) a contract, writing off the investment in the case of a loss, and reaping a reasonably predictable profit in the case of a win.

Commercial ventures, on the other hand, are potentially much more profitable, but the risks are greater, particularly as they are affected by market conditions and competition.

Because of greater constraints and the consequent conservative behavior of management in the government and military areas, some question its entrepreneurial capacity and its willingness to take needed risks in the commercial marketplace. Government contractors are accustomed to bureaucratic procedures and an oversight system that may account for up to 30 percent of the value of a contract. As Montague phrased it, such an organization requires a costly internal auditing system so that external auditors are unlikely to find anything untoward. Commercial organizations obviously cannot be competitive with that kind of burden.

Historically, military contractors have sought to convert by acquiring healthy companies in the commercial area, but there is a scarcity of success stories to cite. An exception may be Amana Refrigeration Inc., acquired by Raytheon Corp. in 1965. But often acquisitions and mergers of commercially and defense-oriented organizations, which seemed logical at the time, did not work as well as their planners had hoped. Sperry-Rand comes to mind, for one. Even when the marriage is not a shotgun marriage—driven by the civilian conversion objective—a promising mating may not work, as is the case of Emerson and Hazeltine. Analysts usually fall back on cultural differences as the best explanation for disappointing results in such mergers.

General Electric Co. envisioned applying its systems engineering strengths to the field of hydroponically grown tomatoes back in 1973. Grumman Corp. marketed aluminum canoes in 1977, and later, metropolitan transit buses. None of these attempts to diversify was notably successful, and all were subsequently sold off.

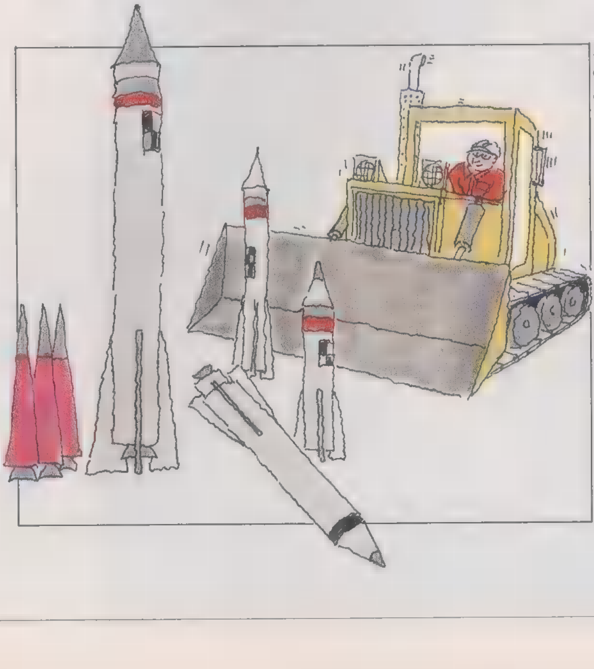
Because military contractors are adept at large projects, Montague said, that's where they should start when thinking about conversion to civilian markets. His own Bethesda, Md.-based company, Martin Marietta, thus has looked to expansion of its postal automation systems business, in which it has incorporated high-technology equipment such as high-speed package scanners. He sees this kind of business as similar to military contracting and an opportunity to move away from military work at the same time. Another example of an organization using its military experience to tackle large civilian projects is Hughes Aircraft Co.'s highway system automation.

Meanwhile, as they hope to start up or acquire profitable commercial product lines, military contractors in the United States are cooperating in a defensive measure aimed at keeping them alive by dividing the shrinking military market. They bid in teams on the smaller number of available projects, so that there will be fewer losers. A single contractor may be part of several bidding teams. Not all observers see that as a healthy trend. Believing there are too many shipyards and too many fighter plane makers for the limited demand, they would prefer the Federal government to facilitate mergers by "whispering in the ears of CEOs," as against imposing an outright ban on team bidding.

The problem of conversion is not confined to the United States. Eastern and Western Europe confront a similar challenge. Eastern Europe and former member nations of the Soviet Union face even more dire and fundamental problems of producing for civilian needs.

Some skeptics, when they analyze economies that were supported heavily by military needs, suggest that a bulldozer may be the best way to convert. Say others, while this may have been successful and even necessary after World War II, the only thing that needs bulldozing now, in the United States or elsewhere, is management.

Donald Christiansen


Gus Sauter

WARC's last act?

At 1992's World Administrative Radio Conference, telecommunications delegates from around the world will allocate spectrum to old and new types of radiocommunications, some of which may eventually displace existing services

P. Saunders, European Space Agency

From Feb. 3 to March 3 more than 1000 delegates representing most of the world's countries will be gathering in Torremolinos, Spain, for the 1992 World Administrative Radio Conference for Dealing with Frequency Allocations in Certain Parts of the Spectrum (WARC-92). The aim of the conference is to set treaty-level agreements on issues affecting the international radio regulations, including spectrum allocations, that will govern wireless communications into the 21st century.

The delegates, most of them telecommunication experts, will decide how to revise the existing radio frequency allocations to accommodate new global satellite and terrestrial communication technologies and services and how to meet the growing demand for existing services. Those decisions will determine which new types of radio services can be implemented as well as how and when, choices that will influence the development of new techologies and their applications for decades to come. But because some of the proposed revisions to the frequency allocations could displace other long-existing services to other frequency bands, they are the focus of international controversy.

WHY SO IMPORTANT? WARC-92 is one of a long series of World Administrative Radio Conferences organized as the need warrants by the International Telecommunication Union (ITU), Geneva, Switzerland. The ITU is the specialized agency of the United Nations whose responsibilities include developing and periodically revising the international radio regulations.

On the average, WARCs occur about every two years. WARC-92 will be smaller than the so-called general World Administrative Radio Conferences (held most re-

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National Aeronautics and Space Administration
Joel Miller Legal Consultant

Artist's concept shows the European Space Agency's proposed European Remote Sensing Satellite ERS-1 over Arctic terrain. The status of allocations for communication links from the earth to such scientific research satellites will be considered at the 1992 World Administrative Radio Conference (WARC-92), to be held this month in Spain.

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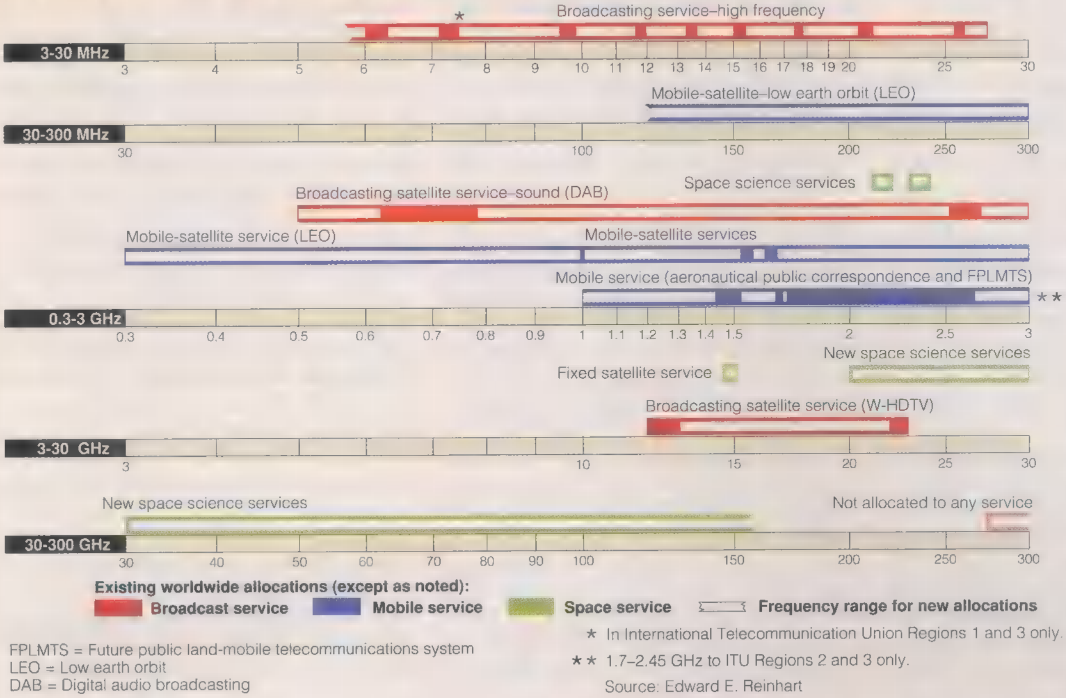
Radio spectrum up for study at WARC-92



Portions of the radio spectrum to be considered for allocations at WARC-92 range from 3 MHz to more than 150 GHz. They cover a range of radiocommunication services, including high-frequency (HF) broadcasting, a variety of mobile communications services, digital audio broadcasting from both terrestrial and satellite systems, wide-rf-band high-definition television, and bands for communications for future operations in space. Some of the proposed new services may, however, displace existing services operating at the same frequencies, making events at WARC-92 more controversial than many earlier conferences.

cently in 1979), at which there is no restriction on either the frequency bands or the radiocommunication services that can be considered for change. On the other hand, WARC-92 will be larger than most of the specialized conferences that have been held, such as WARC-77, which was concerned only with a single service and a single frequency band (the broadcasting-satellite service in the bands between 11.7 and 12.5 GHz).

Although WARC-92 stops short of including all services and all frequencies, it will cover a great part of the spectrum—from 3 MHz to over 150 GHz. It will also cover a wide range of radiocommunication services, particularly those whose existing allocations do not allow for certain new technologies and applications. This year's program also contrasts with some past allocation conferences, which were concerned mainly with accommodating further growth of heavily used services without significantly changing the nature or technology of the service.

For example, WARC-92 will be the first conference to consider commercial communication applications of satellites in low earth orbits (LEO) and highly elliptical orbits (HEO)—those ranging from several hundred to several thousand kilometers above the earth's surface. Previous communication services have largely been offered from satellites in geostationary satellite orbit (GSO)—a 24-hour circular equatorial orbit about 35 900 km above the earth's surface, from which a satellite revolving in the same direction as the earth appears nearly fixed in the sky.

Finally, WARC-92 could well be the last of the WARCs. The ITU is now restructuring itself and its conferences and is also considering possible changes to the procedures for allocating frequencies [see "The International Telecommunication Union," p. 22].

Three new types of services made possi-

Defining terms

Amateur service: a radiocommunication service that licensed operators with no pecuniary interest use for self-training, communication, and technical investigations.

Broadcasting-satellite service (BSS): a radiocommunication service in which signals transmitted or retransmitted by satellites are used for direct reception by the general public.

Broadcasting service: a radiocommunication service in which the transmissions, including sound and television, are intended for direct reception by the general public.

Downlink: a radio link from a satellite to a receiving site on earth or in an aircraft.

Feeder link: a radio link between an earth station and a satellite, conveying information for a space radiocommunication service other than a fixed-satellite service. In the broadcasting-satellite service, all feeder links are uplinks (from the earth to the satellite), but in the mobile-satellite service, feeder links can be both uplinks and downlinks.

Fixed-satellite service (FSS): a radiocommunication service between earth stations at given fixed positions via one or more satellites.

Fixed service: a point-to-point radiocommunication service between specific fixed stations on the earth.

Frequency allocation: a band of radio frequencies identified by an upper and lower frequency limit earmarked for use by one or more of the 38 terrestrial and space radiocommunication services defined by the International Telecommunication Union under specified conditions.

Frequency allotment: the designation of portions of an allocated frequency band to individual countries or geographical areas for a particular radiocommunication service; for a satellite service, specific orbital positions may also be allotted to individual countries.

Frequency assignment: authorization given by a nation's government for a station or operator in that country to use a specific radio frequency channel under specified conditions.

Geostationary satellite orbit (GSO): a circular orbit approximately 35 900 km above the earth, in the plane of the earth's equator, in which a satellite revolves around the earth in the same time that the earth rotates on its axis; thus the satellite appears approximately stationary over one point on the earth.

Low earth orbit (LEO): any orbit around the earth substantially below the geostationary satellite orbit, generally within several hundred kilometers above the earth's surface and usually inclined to the equatorial plane.

Mobile service: a radiocommunication service between mobile and fixed stations, or between mobile stations. Depending on whether one or more of the earth stations are on land, sea, or air, the service would be called land mobile, maritime mobile, or aeronautical mobile.

Mobile-satellite service (MSS): a service that links mobile earth stations with base stations and with one another via one or more satellites.

Radiocommunication: telecommunication using radio waves.

Uplink: a radio link from a site on the earth or from an aircraft to a satellite.

ble by recent technological developments are high on the list for consideration.

FAR-REACHING. Probably the most far-reaching is universal personal telecommunications, wherein every person in the world would be able to carry a handheld wireless telephone that can be reached regardless of location—eventually even far from urban areas, out on the ocean, or in a desert. Officially known as the future public land-mobile telecommunication system (FPLMTS) by the ITU, the service is expected to include satellites in LEO or geostationary orbit to extend existing and future generations of cellular mobile systems to geographical areas where such terrestrial systems are not economically feasible [see ''Mobile communications,'' pp. 27–29].

The second new application is known [redacted] digital audio broadcasting (DAB), [redacted] technology that permits compact-disc–quality signals to be received on handheld or vehicular receivers without the fading and distortion sometimes experienced with AM and FM radio reception at the edges of service areas. DAB systems can employ either terrestrial or satellite transmitters, or a combination of the two. Satellite broadcasting requires a new allocation to the broadcasting-satellite service earmarked for sound (BSS-Sound), which will also accommodate complementary terrestrial broadcasting.

The third upcoming technology, somewhat further in the future, is wide–rf-band high-definition satellite television (W-HDTV). This is the name given to broadcast signals that would be capable of reproducing in the home the full detail of the signal generated in the studio, comparable to the best 70-mm Dolby-equipped movie houses. Some current proposals advocate a new worldwide allocation to the broadcasting-satellite service that can be divided into channels up to 100 MHz wide [see ''Broadcasting,''pp. 24–26].

Besides these three new technologies, other radio applications are vying for first-time allocations. Particularly important for the 21st century is one that would set up communications for future operations in space—for example, high-bandwidth data relay between the international Space Station Freedom and the earth or manned space exploration of the moon, Mars, and other solar system bodies [see ''Space communications,'' pp. 30–33].

In addition, a number of proposals would expand the allocations for existing services that are nearing saturation: those whose lack of spectrum prohibits their being able to accommodate existing or predicted future traffic demands. One example is shortwave or high-frequency (HF) broadcasting. Others include additional allocations to the mobile-satellite services for satellite communications with ships, aircraft, and land vehicles, and to the terrestrial mobile services for aeronautical public correspondence and private land-mobile communication systems.

TRAUMATIC DISPLACEMENTS. If adequate spectrum is allocated to some of these new services or to accommodate expansion of existing services, a few existing services now using the frequency ranges may have to be curtailed or moved to other frequency bands. This possibility arises when systems in the new or expanded service cannot share frequencies—that is, operate on the same frequencies in the same geographical area without radio interference—with the service(s) already allocated to the band.

The International Telecommunication Union

The International Telecommunication Union (ITU) is the United Nations' specialized agency dealing with telecommunications. Its three main purposes are: to maintain and extend international cooperation over improvement and sensible use of telecommunications of all kinds; to promote the development of telecommunication facilities and make them, so far as possible, generally available to the public; and to harmonize the actions of nations seeking these common ends.

Working through international conferences, technical publications, and world exhibitions, the ITU is a union of about 168 member countries (the number changes as formerly separate nations are reunified or parts of formerly united countries achieve independence). With few exceptions, the ITU member countries are the same as those of the United Nations.

The ITU's headquarters near the Place des Nations in Geneva, Switzerland, houses its five permanent organs. One is the ITU General Secretariat, which sponsors the World Administrative Radio Conferences that write the International Radio Regulations governing the use of radiocommunication services throughout the world.

A second is the Bureau of Telecommunication Development, which provides technical support that helps develop telecommunication systems and services in developing nations.

A third organ, the International Frequency Registration Board (IFRB), receives notifications of the frequencies that countries propose to assign to their radio stations and examines them for conformity with the ITU's radio regulations. The IFRB also assists governments in following the regulatory procedures for avoiding harmful interference among stations, and maintains the international frequency register of stations that have completed those procedures.

The other two permanent ITU organs are the International Radio Consultative Committee (CCIR) and the International Telegraph and Telephone Consultative Committee (CCITT). They deal respectively with the technical problems of radio (wireless) communications and the technical problems of telegraph and telephone (wireline) communications.

Through specialized study groups, each Consultative Committee develops international recommendations for radio or wireline communications equipment and protocols, and publishes them in a set of volumes called CCIR or CCITT Recommendations. These recommendations influence telecommunication scientists and engineers, operating administrations and companies, and manufacturers and designers of equipment throughout the world. The "standards" that they contain are regarded as mandatory by some administrations, although the United States and some other countries tend to view them as advisory.

An important part of the CCIR's work is preparing the technical bases for the decisions to be made at a WARC. For WARC-92, this work was carried out over the last two years by a series of Interim Working Parties (IWPs) established by the CCIR Study Groups responsible for the radiocommunication services affected by WARC-92.

WARCs are responsible for reviewing and updating the International Radio Regulations, including the International Table of Frequency Allocations and the procedures for using the allocations. The radio regulations that emerge are also concerned with the standards for equipment, the levels of radiation, and, in general, many of the technical characteristics (antenna patterns, frequency and polarization plans, maximum radiated powers, levels of permissible interference, and the like) of the terrestrial and satellite systems that operate in the frequency allocations.

The agreements reached at a WARC have the status of international treaties. When the heads of delegations from the ITU's member countries sign the Final Acts of a WARC, they are committing themselves to present those Acts to their governments for ratification. In the United States, for example, the Final Acts of a WARC have to be ratified by the U.S. Senate, as do other types of treaties, such as arms control treaties or the law of the sea.

The 1992 WARC may be the last one that will be held under these ITU rules and procedures. Now completely reorganizing its structure, the ITU hopes to improve the processes by which new technologies can be accommodated, to develop standards more quickly, and to hold down costs to the ITU's principal members. Last but not least, the ITU hopes to answer growing demands from developing countries for greater technical assistance in the design and construction of their telecommunications systems (including assured access to the geostationary orbit for their future telecommunication systems).

At the ITU's last Plenipotentiary Conference, held in Nice, France, in 1989, a high-level committee looked at how the ITU might be restructured to better meet those needs and presented its detailed recommendations to the Administrative Council of the ITU in mid-1991. Those recommendations will be considered for adoption at a special Additional Plenipotentiary Conference scheduled for the end of this year. If they are adopted, the new ITU will have three co-equal sectors: development, standardization, and radiocommunications.

Meanwhile, in anticipation of the high-level committee's recommendations, the CCIR's plenary assembly modified the CCIR's own structure in June 1990, streamlining its working methods to facilitate the process by which a recommendation is approved as an international standard.—*Edward E. Reinhart*

For example, certain microwave relay systems in the terrestrial fixed services (communications between two or more fixed points on the earth) would have difficulty sharing with some new broadcasting or mobile-satellite systems without major interference. If new satellite allocations were added, the terrestrial systems would ultimately have to be moved to different frequency bands or perhaps even be converted to nonradio media such as optical-fiber cables. In such cases, plans must be made for the existing services to be phased out over a period of time so that the present system operators and users would have the opportunity to amortize their investment in equipment—a process that in some cases could take up to 20 years.

Decisions at WARC-92 will influence the development of new technologies and their applications for decades to come

Of all the frequency bands to be considered at WARC-92, those in the 1–3-GHz band are the focus of the most intense international controversy. Those frequencies are in demand for FPLMTS, satellite and terrestrial mobile systems, and for digital audio broadcasting. Those demands are of concern to existing services in the 1–3-GHz range, such as the terrestrial fixed and mobile services, certain space research communications, radio-astronomy observations, and amateur or "ham" radio operators.

The difficulty of accommodating some of the new or expanding services without displacing existing ones makes the outcome of WARC-92 more traumatic than in some previous conferences. Before, adding satellite services to bands that up to then had been exclusively terrestrial (such as the fixed-satellite service entering the 4- and 6-GHz bands and the 12- and 14-GHz bands) was not too difficult because analytic and field studies showed that the band could be shared with reasonably small constraints on each type of service.

U.S. PREPARATIONS. Many countries have encouraged involvement from their private sector, but the United States is unique in its solicitation of industry proposals. The U.S. Federal Communications Commission (FCC), Washington, D.C., issued a series of public Notices of Inquiry and established an Industry Advisory Committee to seek industry's views on the questions to be considered at WARC-92 and to seek its reaction to the FCC's views. Taking into account both the recommendations of the FCC's advisory committee and the responses of individual companies to the Notices of Inquiry, the FCC acted as an arbiter among companies and industry segments with different interests and different recommendations on the allocation issues.

On the Government side, the Department of Commerce's National Telecommunications and Information Administration (NTIA), Washington, D.C., which carries out its functions pursuant to a White House Executive Order, has acted in parallel with the FCC to obtain the views of Federal government departments and agencies. The NTIA was assisted by the Interdepartment Radio Advisory Committee (IRAC), made up of representatives of the Federal government's departments and agencies, which made known its constituents' spectrum use.

The FCC and the NTIA next coordinated their evolving positions with each other to resolve major differences before finalizing the U.S. proposals for WARC-92. The Department of State published the U.S. proposals last July and then appointed a group of Government and private sector experts to evaluate the proposals of other nations and prepare detailed position papers on each of the WARC issues. From this group, the State Department also appointed an official delegation to WARC-92.

INTERNATIONAL ALLIANCES. Outside the United States, every country prepared its proposals in different ways. Each has its own mix of interests. Many of them formed alliances between the industrial groups and between the government agencies.

Most European countries have a post, telephone, and telegraph administration (PTT), which has its views about how the WARC-92 allocation issues should be resolved. There are also broadcasters and, to a growing extent, privately operated systems of other types, both mobile and point-to-point. In most European countries, the military also has a strong voice in any allocation action.

The PTTs of 32 Western and Eastern European countries are bound together in an international regional organization known as the Conférence Européenne des Administrations des Postes et des Télécommunications (CEPT), Berne, Switzerland. In preparation for WARC-92, CEPT established an *ad hoc* working group that has developed a set of European common proposals on each of the major WARC-92 issues. In developing these joint proposals, it was not always possible to gain the agreement of all 32 CEPT countries.

Although the parallel is not exact, the North and South American counterpart to CEPT is the Conferencia Interamericana de Telecomunicaciones (Citel). It reports to the Organization of American States, headquartered in Washington, D.C., and its members are the Central and South American countries, plus the United States and Canada.

One of Citel's permanent technical committees, PTC-III, established an interim working group responsible for coordinating the Americas' views on WARC-92 issues. The report of this group, which was published last May, provides a common Citel view on many issues.

In Asia, the nearest counterpart to CEPT and Citel is the Asia-Pacific Telecommunity (APT), headquartered in Bangkok. This 22-nation group cosponsored a WARC-92 preparatory seminar last August, but by the end of 1991 had not published an Asian common proposal.

Previously, a number of nations not aligned with the formal organizations—including Cuba, India, Yugoslavia, and certain developing North African countries—have held conferences before and during a WARC to develop common positions on the issues. It is likely they will repeat this practice during WARC-92.

In many parts of the world, there are also private-sector systems operators that have their own regional organizations and their own views on certain issues. One example is the European Broadcasting Union (EBU), which includes most of the broadcasters of all the European nations. Through its technical center in Geneva, the EBU has analyzed the technical aspects of the allocation proposals for all the broadcasting issues. The union has also made suggestions on what should be done, not always agreeing with CEPT.

Asian and Middle Eastern counterparts of the EBU, such as the Asia-Pacific Broadcasting Union (ABU), headquartered in Kuala Lumpur, Malaysia, and the Arab States Broadcasting Union (ASBU), in Tunis, Tunisia, are making their own preparations for WARC-92.

In addition, several international and regional organizations concerned with specific types of telecommunications services are also preparing positions for WARC-92. Among the worldwide groups are the International Maritime Satellite Organisation (Inmarsat), London; and the International Telecommunication Satellite Organization (Intelsat), Washington, D.C.; the International Maritime Organisation (IMO), London; and the International Amateur Radio Union (IARU), Newington, Conn.

In addition, there are certain specialized agencies of the United Nations. Examples are the International Civil Aviation Organization (ICAO), Montreal, and the World Meteorological Organization (WMO), Geneva, Switzerland.

The regional organizations include the European Community (EC), Brussels, Belgium; the European Organization for the Exploitation of Meteorological Satellites (Eumetsat), Darmstadt, Germany; and the European Space Agency (ESA) and European Telecommunication Satellite Organization (Eutelsat), both in Paris.

Broadcasting

Among the hot issues: broadcasting at HF, and digital audio and high-definition television from satellites

Three major allocation issues involving the broadcasting and broadcasting-satellite services will be discussed at the 1992 World Administrative Radio Conference (WARC-92): expansion of frequencies for conventional high-frequency (shortwave) broadcasting; new frequencies for both satellite and terrestrial digital audio (radio) broadcasting to handheld and automobile receivers; and new frequencies for studio-quality high-definition television broadcasting from satellites.

ENDING HF SHORTAGE. Expanding the existing high-frequency (HF) allocations in the range of 5950–26100 kHz is intended to end the persistent shortage of spectrum allocated exclusively to domestic and international shortwave radio broadcasting. Exclusive bands are needed because, given the atmospheric propagation problems and interference in that range, the very high-powered transmitters required for reasonably reliable service to portable receivers make it difficult for broadcasters to share the same frequencies with other services having HF allocations. Those other services include the fixed service (for point-to-point communications), the mobile services (aeronautical, land, and maritime), the amateur and amateur-satellite services, the standard frequency and time signal service, and the frequencies reserved for radio astronomy observations. Now, the spectrum allocated exclusively to the broadcasting service totals 2930 kHz worldwide (3130 kHz in International Telecommunication Union (ITU) Regions 1 and 3). This total is divided among narrow bands near 6, 9, 11, 13, 15, 17, 21, and 25 MHz (plus one near 7 MHz in Regions 1 and 3).

Among the technical issues to be weighed at WARC-92 is assigning HF broadcasts more but narrower channels than those presently employed. One way of creating narrower channels is to change the modulation method. Since virtually all HF broadcasting today uses double-sideband amplitude modulation, channel bandwidth could be nearly halved if transmissions were converted to single-sideband modulation.

Edward E. Reinhart Consultant

Various standards organizations generally agree that HF broadcasters should someday convert to single sideband; there is less agreement on when and how the conversions should be made, given the fact that an estimated 520 million double-sideband HF receivers are in the hands of listeners.

Most countries that have published their proposals for WARC-92 support the provision of at least some new spectrum for HF broadcasting, nearly all of it in bands formerly allocated to the fixed service, which would be given up to 15 years to be reaccommodated to another band. But there is little agreement on the amount of spectrum to be allocated, exactly where it should be added, when the new allocations should take effect, or what technical constraints should apply.

The U.S. proposal, for example, calls for 1325 kHz of additional spectrum for HF broadcasting in Region 2 and 1125 kHz in Regions 1 and 3; the European Common Proposal, endorsed by most of the members of the European Conference of Postal and Telecommunications Associations (CEPT), Berne, Switzerland, calls for 1500 kHz more spectrum.

Both proposals encourage single-sideband technology, with the complete cessation of double-sideband transmissions occurring after the turn of the century.

> Many view digital audio broadcasting from satellites as the most challenging technology and controversial allocations issue

A few countries propose that no more than 1000 kHz of new spectrum be allocated to HF broadcasting, and others propose that there be no new allocations at all.

DIGITAL AUDIO FOR ALL. Of the three broadcasting issues, the proposal for digital audio broadcasting (DAB) is perhaps the most exciting. Digital coding and modulation techniques that have already been developed and demonstrated will permit compact-disc-quality stereo signals to be broadcast from either satellite or terrestrial transmitters to portable and vehicular receivers without the fading typical of car-radio reception near the edge of broadcast service areas.

With satellite transmitters, such signals can be made available to the entire population of a country instead of to just those within range of terrestrial transmitters.

Moreover, the same digital techniques permit monophonic signals of lower audio quality (equivalent to either standard AM or FM broadcasting) to be broadcast in narrower channels to entire continents with near-perfect reliability. That leads to the possibility that satellite DAB could provide international broadcast services comparable to, but more reliable than, those now provided in the HF band. Indeed, if satellite DAB met at least some of the international broadcasting requirements, additional spectrum being sought for HF broadcasting might ultimately prove unnecessary.

DAB is a challenging broadcasting technology because vehicular and portable receivers provide almost no antenna gain for boosting the power level at the receiver's input. Moreover, foliage absorbs the signals and buildings reflect them, causing the signal level to vary rapidly in time (fade). Thus, a satellite transmitter must be very powerful (tens to hundreds of watts per stereo channel, depending on downlink frequency and antenna beam coverage).

Most systems envisioned for satellite DAB propose to use satellites in geostationary orbit, although the European Space Agency, Paris, has proposed satellites in highly elliptical orbits to beam lower-power signals (10 W or less per stereo channel) to countries above about 40 degrees northern latitude.

Most of the proposals for satellite DAB also envision using complementary terrestrial transmitters as repeaters or "gap-fillers" that rebroadcast the satellite signal from towers in the urban area. This technique would help to overcome the higher man-made rf noise levels and the propagation problems in cities (shadowing and reflections by buildings in downtown areas). Thus, the satellite transmitter power can be reduced to the lower level needed for reception in rural areas.

To accommodate DAB for satellite and complementary terrestrial use, the ITU's International Radio Consulative Committee (CCIR) has put the need for bandwidth at a total of 60–130 MHz. Therefore, WARC-92

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will be seeking an allocation of about that size in the frequency range between 500 MHz and 3 GHz, together with the necessary feeder links at higher frequencies in the fixed-satellite service.

For economic and technical reasons, the CCIR concluded that a band around 1.5 GHz—right in the middle of the suggested frequency range—appears to be the most attractive for satellite DAB. At the low end of the frequency range, the size and cost of the satellite antenna for a given beam coverage can become prohibitively large because antenna size is inversely proportional to frequency. Similarly, at 3 GHz, about four times as much satellite power is required as at 1.5 GHz because the gain of the simple portable and vehicular receiving antennas remains essentially constant while the free-space path loss from the satellite to the earth increases with the square of frequency.

Similarly, transmitter power requirements and costs for a given terrestrial coverage increase rapidly with frequency and escalate the cost of the overall system. Thus, a frequency at or below 1.5 GHz also appears preferable for terrestrial DAB transmitters, whether used for a stand-alone system or as gap-fillers to complement satellite DAB.

POTENTIAL THREAT? The proposed frequency allocations for DAB are controversial because they pose a threat to the users of bands allocated to other services in the 0.5–3-GHz frequency range. The threat rises from the fact that DAB—and especially satellite DAB—like all other broadcast transmissions, cannot share frequencies with other services in the same geographic area without either causing or suffering from harmful radio interference.

For example, Australia, Brazil, Canada, Mexico, and others favor an allocation for the broadcasting-satellite service and complementary terrestrial-broadcasting service just below the present mobile-satellite service downlink allocations at 1.530–1.559 GHz.

However, frequencies below 1.530 GHz are already in heavy use for other services. In the United States, for example, the band 1.427–1.530 GHz is used heavily for aeronautical mobile telemetry in the flight testing of missiles and aircraft. In Japan, this same band is earmarked for cellular land-mobile services. In Canada, it is used for microwave relay systems in the terrestrial fixed service. And certain South American countries have just installed new terrestrial radio systems at those frequencies.

Many other countries, including many members of CEPT, plus India, Japan, and Russia, support an allocation for DAB within the range from 2.50–2.69 GHz, which is already allocated to the broadcast satellite service, albeit not specifically to DAB. But in the United States, those frequencies are already heavily used by both the Instructional Television Fixed Service (ITFS) used by universities, and the Microwave Multipoint Distribution Service (MMDS)—a commercial "wireless cable" television service available in some areas.

In response to all these difficulties, the United States proposes to allocate the band 2.31–2.36-GHz for DAB; the existing primary allocations to the fixed, mobile, and radiolocation services would be reduced to secondary status (allowed to use the band only if they did not interfere with or require protection from DAB transmissions) in 1997 or when DAB systems were implemented, whichever occurred later.

Apart from the frequency-band controversies, DAB is contentious because it would compete with existing terrestrial AM and FM broadcasting stations for listeners.

To be sure, broadcasters in Canada, Europe, and the United States see the development of purely terrestrial DAB as an opportunity for existing AM and FM stations to improve service and coverage beyond that possible with analog techniques.

Nonetheless, implementing a terrestrial DAB system would require a large investment in new transmission equipment to reach an audience that would be quite small until DAB was widely installed. For that reason, some AM and FM station operators resist its introduction.

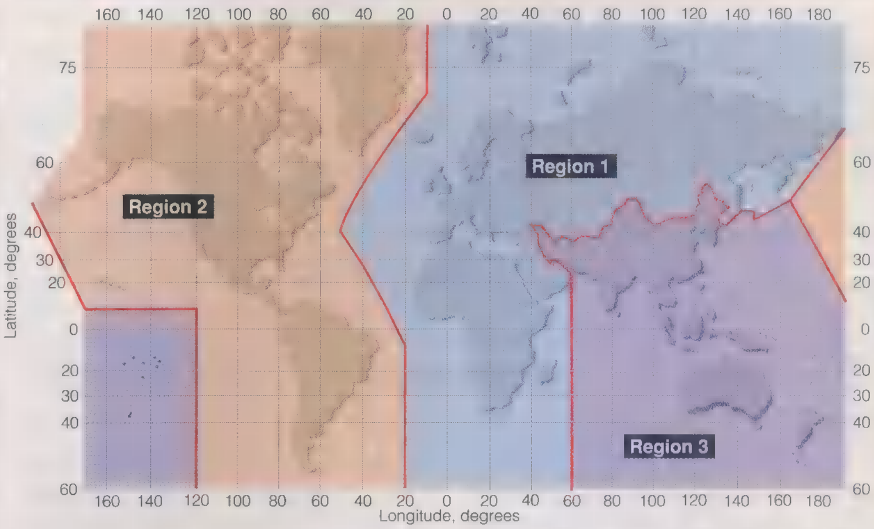
It has even been suggested that neither satellite nor terrestrial DAB requires WARC-92 to create new frequency allocations. On the satellite side, it has been argued that a digital radio signal of less than CD quality could be broadcast from satellites to portable and vehicular receivers on frequencies allocated to the mobile-satellite service [see "Mobile communications," pp. 27–29].

On the terrestrial side, it is believed that existing allocations to the broadcasting service could be used for DAB. In Europe, for example, it is planned to introduce terrestrial DAB within channels previously assigned to terrestrial television. In the United States, work is progressing on spread-spectrum techniques for broadcasting high-quality audio programming in the FM broadcast band without interfering with existing FM transmissions.

NEXT-GENERATION SATELLITE HDTV. Over the past few years several alternative analog-signal formats have been developed for representing high-definition television (HDTV) pictures in a narrow rf bandwidth—narrow enough for broadcast in typical satellite channels having a bandwidth from 24–36 MHz. Examples include the MUSE-E (multiple sub-Nyquist sampling encoding) system developed in Japan, the HDBMAC (a high-definition version of a particular multiplexed analog components format) system in the United States, and the HDMAC system in Europe. All these formats offer a wide-screen picture (having a 16:9 ratio of width to height compared with the 4:3 of ordinary television), resolution greatly improved over ordinary television, and CD-quality digital stereo sound.

The combination of limited channel bandwidth and inherent limitations of analog-signal processing and modulation techniques, however, introduce artifacts and restrict resolution. Thus, picture quality falls well below that originating in the studio, especially in scenes with rapid motion.

Meanwhile, developments in digital techniques for encoding and modulating video signals now promise to outdo the analog formats by allowing superior HDTV picture quality to be achieved in the same rf channel bandwidths. In addition, it has been demonstrated that, with wider rf-channel bandwidths (up to 140 GHz), picture quality seemingly as good as a studio standard can be received over satellite links. This latter type of digital HDTV has been labeled wide rf-band HDTV (W-HDTV) to distinguish it from the analog formats already developed. Moreover, with



Source: International Telecommunication Union

The world is divided into three regions by the International Telecommunication Union. Spectrum allocations to radiocommunication services are not necessarily the same in all three regions, although the 1992 World Administrative Radio Conference will attempt to make the allocations for some crucial services consistent worldwide.

further development of digital coding and modulation techniques, such studio-quality images may be possible in today's narrow-rf-band channels.

VIABLE CANDIDATES. Between 12.7 and 23 GHz—the range of spectrum WARC-92 was instructed to consider for W-HDTV—current proposals have fastened on three possibilities. In addition, just above the 23-GHz upper limit, the United States and Japan have proposed a fourth option.

The first possibility, favored by Brazil, Canada, Mexico, and Venezuela, is to allocate the 17.3–17.8-GHz band to the broadcasting-satellite service for W-HDTV. There is one big problem with this option, though: the band has already been allocated to—and the channel assignments planned for—the uplinks or feeder links to direct-broadcasting satellites for conventional television in the 12-GHz band.

This is one of the rare cases in which the same band has been proposed for use in both directions of transmission: as 17-GHz feeder links to 12-GHz direct-broadcasting satellites whose feeder links are to be provided at another frequency. That need not cause interference if the 17-GHz uplink transmitters for the 12-GHz direct-broadcasting satellites are well isolated in areas likely to receive 17-GHz W-HDTV broadcasts.

Many planners of 12-GHz direct-broadcasting satellite systems see no problem with this since they intend to feed their satellites from only a limited number of fixed sites that could be isolated or shielded. However, other direct-broadcasting-satellite system applicants foresee a need to feed transmissions of live breaking news or sports events directly to their broadcast satellite from transportable earth stations on location; they do not want to "backhaul" the signal to the studio, which would then uplink it from a fixed feeder-link site. Largely in response to this need, the United States has rejected the 17.3–17.8-GHz band for W-HDTV.

Outside ITU Region 2, most countries, including all the CEPT administrations, plus Australia and Russia, propose a second option for accommodating W-HDTV: the band 21.4–22.0 GHz. This 22-GHz band is currently allocated to the fixed and mobile services only. The CEPT proposal would defer implementation of the broadcasting-satellite service allocation until the year 2005 (except for experimental use that did not cause interference) to protect the already well-developed fixed service in that band and allow for its orderly transfer to another band.

Indonesia and other members of the Asia-Pacific Broadcasting Union have considered a third option for W-HDTV: the extension to ITU Region 1 of the existing 22.5–23-GHz broadcasting-satellite allocation already available in Regions 2 and 3.

There are, however, serious technical problems with this 23-GHz band. It is located so near a frequency that atmospheric water vapor strongly absorbs that the satellite signal power must be quite high to overcome both atmospheric absorption and losses during rain.

Moreover, the 23-GHz band presents formidable frequency-sharing problems because it is already allocated in all the ITU regions to the fixed, mobile, and intersatellite services, and to radio astronomy observations. A broadcasting satellite could not effectively share the frequencies with those other services, not only because its high broadcasting power could interfere with receivers in the other services, but also because the fixed-service transmitters on the earth would interfere with the broadcast receivers on the satellite.

A fourth option, from 24.65–25.25 GHz, has been proposed by the United States and Japan. Although this band lies above the 23-GHz cutoff specified for consideration at WARC-92, it does not displace existing fixed-service operations at either 22 or 23 GHz, nor does it cause difficulties with the feeder-link plan inherent in the 17-GHz option.

Although the 25-GHz band is currently allocated to the radionavigation service, that allocation is little used and reallocation to the broadcasting-satellite service would cause no significant displacement. Thus the 25-GHz band is the only one of the four proposals for W-HDTV broadcasting that does not require a long delay before the allocation could be implemented.

The only drawback is that the 25-GHz option does require the highest satellite power of all the options—about 5.5 dB more than at 17 GHz and about 1 dB more than at 22 or 23 GHz under typical conditions—but the impact on system costs is not nearly so high.

LONG LEAD TIME. All countries recognize that wide-band satellite HDTV service probably will not come into service for 10 years or more. But that is precisely why European countries pressed to get it on the WARC-92 agenda: a long lead time was viewed as vital not only to developing the technology, but also—with the exception of the 25-GHz band—to allowing the time needed to make the chosen band available.

WARC-92 and amateur radio

Although the amateur or "ham" radio community is not seeking additional allocations at the 1992 World Administrative Radio Conference (WARC-92), several of the items on the WARC-92 agenda, if enacted by the International Telecommunication Union, could partially displace existing amateur allocations. Thus amateurs are compelled to participate to protect their interests.

Even though the only entities entitled to vote at a WARC are duly accredited delegations of member nations, the world's amateurs do have a voice.

First, they will be represented directly at the WARC by the International Amateur Radio Union (IARU), a body representing all amateur groups and the approximately 2.1 million licensed amateurs worldwide. The IARU is expected to have official observer status at the conference, acting in an advisory capacity.

Second, amateurs have made their views known to the delegations of their host countries. In the United States, for example, two channels were available for such input. One was the Federal Communications Commission's (FCC's) Industry Advisory Committee, which explored the issues presented by the WARC-92 agenda and developed an industry position on them. Participating extensively in that committee's work was the American Radio Relay League (ARRL), the national amateur radio organization.

The other U.S. channel available was the FCC's three Notices of Inquiry, which were issued to solicit comments from the public at large, and to which the ARRL and other interested parties responded. Because the agenda includes items relevant to satellite communications, the Radio Amateur Satellite Corporation (Amsat), a Washington, D.C.-based group, similarly offered comments.

One of the WARC-92 proposals of interest to amateurs concerns allocations at 7 MHz, also known to the amateurs as the 40-meter band. In addition to the exclusive allocation of 7.0–7.1 MHz, amateurs currently have a primary allocation of 7.1–7.3 MHz in the ITU's Region 2 (North, Central, and South America), while international broadcasting is permissible in the same frequency range in ITU Regions 1 (Europe, Africa, and the former USSR) and 3 (Asia and Australia). Given the great disparity in transmitter power between the amateurs and the broadcasters—up to three or four orders of magnitude—amateurs have found much of the 40-meter band difficult to use in the evening hours—"an incompatible allocation," according to the FCC.

To resolve the conflict, the United States—with the agreement of the amateur community—is proposing a 100 kHz shift down of the amateur band, granting the international broadcasters an exclusive allocation above that range. Specifically, hams would receive a primary allocation of 6.9–7.0 MHz; land-mobile users would share it on a secondary basis as long as their transmissions do not interfere with amateurs. Amateurs would also receive an exclusive allocation of 7.0–7.2 MHz worldwide. Broadcasting in turn would have 7.2–7.3 MHz exclusively worldwide.

Another area of concern to amateurs is alternative proposals by U.S. entities regarding the use of 2.31–2.36 GHz for digital audio broadcasting and 2.39–2.43 GHz for geostationary satellite uplinks for the mobile-satellite service. Currently, 2.3–2.45 GHz is allocated to amateurs on a secondary basis worldwide. Hams are particularly worried about any interference that may result from these proposed uses and new restraints that could affect amateur satellite operations.

Regardless of the outcome of the WARC-92 deliberations, any changes would not be implemented for several years, giving amateurs or other users plenty of time to phase in new equipment and adjust to changes in frequency allocations. All the same, amateurs would prefer to avoid any major dislocation of their operations. —*Joel Miller*

Mobile communications

WARC-92 must find room in already crowded bands for new worldwide mobile services and expanded existing services

Probably the most important—and most challenging—allocation issue facing the 1992 World Administrative Radio Conference is determining how to provide additional spectrum for both existing and entirely new mobile services. At least six types of mobile systems will be seeking new or expanded allocations: three involve satellites and three rely on primarily terrestrial techniques. All but one will be forced to compete for allocations in the same crowded 1–3-GHz frequency range.

The satellite systems differ mostly in the types of satellites used and the range of services to be offered. Some, using satellites operating above 1 GHz in geostationary orbit, are existing and planned global, regional, or domestic systems that will provide a full range of voice and data services to handheld or mobile terminals on land, at sea, and in aircraft. Others will offer comparable services from satellites in low earth orbit in the 1–3-GHz band. The third type will provide a more limited range of services at lower data rates and lower cost from smaller low-earth-orbit satellites using no more than 5 MHz of spectrum below 1 GHz.

Not only would new allocations to the mobile-satellite stations permit the introduction of radically new services such as worldwide personal telecommunications, but they also would alleviate the pressure on existing allocations.

At WARC-92, the terrestrial systems to be considered, all in the 1–3-GHz range, are: a future public land-mobile telecommunication system able to link users of personal handsets anywhere in the world; greatly expanded private land-mobile radio systems; and a worldwide public telephone service for airplane passengers. In contrast to the satellite services, much of the 1–3-GHz range is already allocated to the land-mobile services, so it may be enough just to designate which specific parts of the existing allocations are to be used by these systems.

Edward E. Reinhart Consultant

Of all the mobile issues, probably the most urgent is how to accommodate the new satellite systems above 1 GHz that will be using both low earth orbits and the geostationary satellite orbit.

Excluding 1 MHz of spectrum reserved for distress and safety satellite communications with mobile terminals, only a total of 28 MHz of downlink spectrum (1.530–1.559 GHz) and 33 MHz of uplink spectrum (1.6265–1.6605 GHz) is currently available for mobile-satellite systems, such as the global Inmarsat system, which uses geostationary satellites to provide voice and data to maritime and other mobile terminals using comparatively nondirective antennas. Extrapolating from the growth rate of the last few years, the projected spectrum requirements for Inmarsat and planned future maritime, aeronautical, and land mobile-satellite systems are expected to greatly exceed the spectrum now allocated.

Most proponents of new mobile-satellite service allocations believe there should be a minimum total of at least 89 MHz of spectrum—with a likely requirement of 164 MHz—in each direction of transmission, assuming that the spectrum is not shared with other services.

Proponents differ in whether the existing allocations should become generic (allocating the same band to maritime, aeronautical, and land mobile-satellite services together) or whether separate spectrum should be earmarked for no more than two of the three. The generic approach, with a provision for the pre-emption for safety services, is favored by Canada, the United States, and some other countries for both existing and new mobile-satellite service allocations; most of the rest of the world proposes to maintain the *status quo* for existing allocations.

> If proposed personal telecommunications systems are to become reality, WARC-92 must resolve some knotty sharing problems

LOW VERSUS HIGH. An issue new to any WARC is accommodation of mobile-satellite systems using satellites in low earth orbit (LEO) instead of geostationary orbit (GSO).

The LEO issue originated in the United States in response to applications by several system operators and involving two types of LEO mobile-satellite systems [see table].

The first type, sometimes dubbed "little LEO" systems, would provide low-cost, low-data-rate (up to 10 kb/s), two-way digital communications, and position location services to pocket-sized portable and mobile terminals at frequencies in the VHF band below 400 MHz.

Such systems would employ 2 to 24 so-called "lightsats"—small, inexpensive satellites launched into orbits 800–1300 km above the earth and capable of serving the world. WARC-92 will weigh possible allocations of up to 5 MHz in a frequency band below 1 GHz to accommodate these little LEO systems on the basis of appropriate sharing criteria.

The other major type of system employing satellites in low earth orbit that would operate above 1 GHz are sometimes called "big LEO" systems. In addition to traditional voice and a wide range of moderate- to high-speed data services (up to a few megabits per second), the big LEO systems would also provide worldwide services in personal communications to handheld terminals like those used in cellular mobile systems.

The first applicant for a big LEO system was Motorola Satellite Communications Inc., Chandler, Ariz., with its 77-satellite Iridium system—named after the element iridium, whose atom has 77 orbiting electrons. Motorola was followed by applications from a number of other companies offering a similar mix of services but using different numbers of satellites and types of orbits.

Some companies have argued that all the services envisioned for the big LEO systems can be provided by three satellites in geostationary orbit, each with many spot beams. Such a system concept called Tritium, in part because that isotope of hydrogen has three electrons in orbit, was advanced by Hughes Aircraft Co., El Segundo, Calif.

ALLOCATION PROPOSALS. Most countries agree on the addition of at least 5 MHz of downlink spectrum immediately below the existing downlink band at 1.530–1.559 GHz in order to make the spectrum in this band equal to that in the uplink band at 1.6 GHz.

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There is also general agreement on the provision of ■ matched pair of uplink-downlink bands for ITU Regions 1 and 3 in the range 2.50–2.59 GHz. The amount and exact location of the bands and whether or not they should be generic must be resolved at WARC-92.

Among International Telecommunication Union (ITU) members, as opposed to international organizations such as Inmarsat, only Brazil, Canada, and the United States have proposed substantial new allocations to the mobile-satellite service in the frequency range of 1.6605–2.5000 GHz. Within that range, the U.S. proposal for a bidirectional allocation between 1.85 and 1.90 GHz is innovative in that it would permit the future identification of sub-bands that, subject to adequate sharing criteria, could accommodate services from either LEO or GSO satellites or both.

The United States and one or two other countries have also proposed to add the mobile-satellite service to the existing radiodetermination satellite service (RDSS) bands at 1.610–1.6265 GHz for uplinks and 2.4835–2.5000 GHz for downlinks. This band is viewed ■ a promising candidate for meeting the near-term requirements of big LEO systems. Disputes still remain over the efficiency with which mobile-satellite systems could use the RDSS band, given that the radio regulations include footnotes designed to protect other services in the same band and force satellite systems to comply with power flux density limits in the downlink band.

More generally, experts disagree on how practical it would be for low-earth-orbiting systems to share frequencies with systems in geostationary orbit. The radio regulations and the current recommendations of the ITU's International Radio Consultative Committee (CCIR) are silent on the means and the extent to which they might coexist.

FUTURE PUBLIC LAND MOBILE. Of all the types of mobile communication systems for which WARC-92 is to allocate spectrum, the future public land-mobile telecommunication system (FPLMTS) is likely to have the greatest impact on the way the public telephone network is accessed and used. FPLMTS is intended to become ■ worldwide personal communications network, offering all the services already available through telephone networks—including voice, facsimile, and data.

The phrase "land mobile" is rather a misnomer. FPLMTS is envisioned as being accessible not only to mobile users on land (including automobiles and high-speed trains), but also on ships, in the air, and to fixed terminals. FPLMTS will permit connection to the system by satellites operating in the mobile-satellite services band. Both the personal and mobile stations will be able to connect into the system by radio at any time and from any place in the world [see figure]. The wireless system is expected to be especially valuable to developing countries where it could be used to establish ■ telephone system quickly.

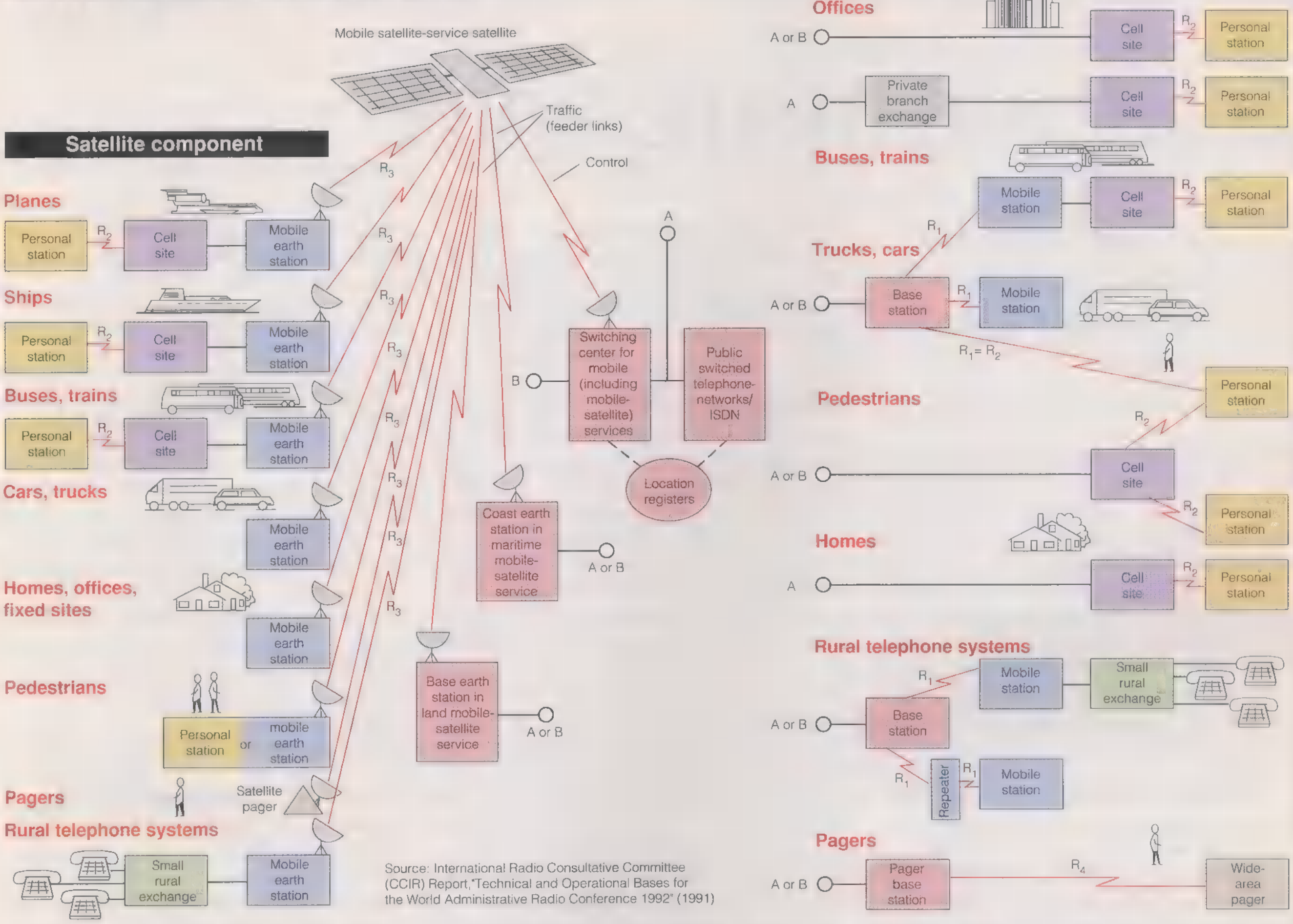
Extensive propagation studies and technical considerations reported to the CCIR in-

Proposed low-earth-orbit (LEO) mobile-satellite communication systems

System	Company	No. of satellites	Orbits	Altitude, km	Frequencies, MHz	Services	Type of signal
[illegible]							
Leosat	Leosat Inc., Ouray, Colo.	18	3	1000	148–149 uplink, 137–138 downlink	Two-way communication and radio location for intelligent vehicle highway system	N.A.
Orbcomm	Orbital Communications Corp., Fairfax, Va.	20	3 inclined, 2 polar	970	148–148.9 up; 137–139, 400.1 down	Two-way communication and radio location; slow, low-cost data transmission	N.A.
Starnet	Starsys Inc., Washington, D.C.	24	24 random	1300	148–149 up, 137–138 down	Global two-way communication, data, radio location	Rule making for very high frequencies
Vitasat	Volunteers in Technical Assistance (VITA), Arlington, Va.	2	Single, circular	800	137.7 down, 400.2 up; or 400.2 down, 149.8 up	Data services and file transfer primarily for developing nations	N.A.
[illegible] GHz							
Aries	Constellation Communications Inc., Herndon, Va.	48	4 polar	1018	1610–1625.5 up, 2483.5–2500 down; 5150–5216 down, 6525–6541 up	Position determination and reporting, two-way telephony, dispatch voice, facsimile, and data collection, distribution, and control services	SS/CDMA
Ellipso	Ellipsat, Washington, D.C.	24	3 highly elliptical	2903 by 426	1610–1626.5 up, 2483.5–2500 down	Will connect to a cellular phone to convert 800-MHz cellular to the 2.5-/1.6-GHz RDSS bands	SS/FDMA
Globalstar	Loral Cellular Systems Corp., New York City	48	8	1389	1610–1626.5, 2483.5–2500, 5199–5216, 6525–6541, all bidirectional	RDSS, voice, data communications	SS/CDMA
Iridium	Motorola Inc., Chandler, Ariz.	77	11	765	1610–1626.5 bidirectional; 27.5–30 up, 18.8–20.2 down, 22.5–23.5 cross-link between satellites	Worldwide cellular telephony and portable phone service	N.A.
Odyssey	TRW Inc., Redondo Beach, Calif.	12	3 inclined circular	10 370	1610–1626.5 up, 2483.5–2500 down; 19 700–20 000 down, 29 500–30 000 up	Voice, radio location, messaging, data services	SS/CDMA

CDMA = code-division multiple access/spread spectrum.
FDMA = frequency-division multiple access.
N.A. = not available.
RDSS = radiodetermination satellite service.
SS = spread spectrum.
Source: Bruno Pattan, Federal Communications Commission; Office of Technology Assessment, *WARC-92: Issues for U.S. International Spectrum Policy*, November 1991

Architecture for future public land-mobile telecommunication system (FPLMTS)



The architecture of the future public land-mobile telecommunication system (FPLMTS) includes the functions of cordless telephony, paging, wireless pay phones, private branch exchanges, and rural radio and telephone exchanges among terminals on land, at sea, and in the air. Calls within the mobile system would be routed to and from the existing wired public switched telephone network through satellites and terrestrial links using four kinds of radio interfaces (R_1 through R_4). One of the tasks of the International Radio Consultative Committee (CCIR) group responsible for FPLMTS at WARC-92 is to develop standards for those and other interfaces. A and B are the connections to the public switched telephone network, A directly into the network and B through an independent mobile switching center. The cell sites to which several personal stations have access are within the vehicles and may or may not be within the buildings.

dicate that a frequency allocation in the already crowded band of 1–3 GHz is most suitable for FPLMTS. The CCIR estimates the minimum spectrum required to be 230 MHz (170 MHz for mobile stations and 60 MHz for handheld personal stations) and should become available early in 1998.

In the view of some countries, the spectrum needs for FPLMTS could be handled within the existing allocations to the terrestrial mobile services.

PRIVATE LAND-MOBILE SYSTEMS. WARC-92 must also provide spectrum for the rapidly growing needs of private land-mobile systems. Such private systems are essential to a medley of applications in industry, manufacturing, private safety (police and ambulance), and fleet transportation and the number is growing at an annual rate of 7–10 percent.

Estimates of the additional terrestrial mobile allocations required to accommodate this growth range from two 35-MHz band segments in Europe to two 50-MHz band segments in Japan. As with the spectrum needed for FPLMTS and for aeronautical public correspondence, WARC-92 has been instructed to find a solution between 1 and 3 GHz.

In ITU Regions 2 and 3, the existing mobile sevice has a primary allocation of 1.7–2.69 GHz.

In ITU Region 1 (Europe, Africa, and the former USSR), though, the existing primary allocation to the mobile service is largely in the range 2.45–2.69 GHz. For this reason, the European Common Proposal, endorsed by most of the 31 countries of CEPT, is to upgrade the present secondary mobile allocations in Region 1 to primary status in the range 1.7–2.45 GHz, thus making the existing Regions 2 and 3 mobile allocation worldwide.

AERONAUTICAL PUBLIC CORRESPONDENCE. A 1987 WARC on mobile communications provided two 1-MHz bands (1.593–1.594 and 1.6255–1.6265 GHz) for experimental development of a terrestrial-aeronautical public correspondence (APC) system—that is, a system allowing public telephones on aircraft to connect to the land-based public switched telephone network through ground stations. It was feared, however, that such a system might interfere with certain radionavigation systems in those bands.

The United States and some other countries have already established APC systems in the 849–851- and 894–896-MHz bands and propose that those bands be allocated worldwide. In contrast, the European Common Proposal suggests doing away with these bands and designating the band 1.670–1.675 MHz for ground-to-air APC transmissions and the band 1.800–1.805 for air-to-ground APC links. WARC-92 is charged with finding a common pair of bands to permit a worldwide APC system of about 2 MHz in each direction, air to ground and ground to air. Whether a common worldwide solution can be found remains to be seen.

Space communications

Adequate spectrum must be allocated for future space communications and the development of as yet unforeseen technologies

The 1992 World Administrative Radio Conference (WARC-92) will hear six proposals for enhancing or expanding the electromagnetic spectrum allocated for communications supporting research in space. They will cover extravehicular activities, space operations, data relay links, deep space interplanetary probes, future planetary missions, and earth exploration satellites.

Decisions made at WARC-92 either to accept or reject the proposals could determine the direction aerospace communication engineers will take in research, development, and production for the rest of this decade. After all, if a certain region of the spectrum is not available for a particular use, no company will devote resources to developing communications equipment at those frequencies; similarly, if certain allocations are made, those bands represent new opportunities for R&D.

INTERNATIONAL AGREEMENT. Although some of the six proposals for allocations to the space science services originated in specific nations, all have first been reviewed by the Space Frequency Coordination Group, which has resolved any differences. Meeting annually, this group is an informal association of some 30 of the world's civilian space agencies formed during the general WARC of 1979 [see table on opposite page].

Chartered by the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA), the group coordinates the ways in which existing space service allocations are used, and develops and harmonizes the requirements for spectrum allocations needed to support existing and future communication links for scientific spacecraft.

At WARC-92, the group will work toward service allocations around 2 GHz, and toward securing new allocations for 400 MHz, 26 GHz, 32 GHz downlink (from the spacecraft to the earth), 34 GHz uplink (from the earth to the spacecraft), 37 GHz downlink, 40 GHz uplink, 61 GHz, 74–84 GHz, and 157 GHz.

Robert M. Taylor
National Aeronautics and Space Administration

IMPROVING 2 GHz. Perhaps of primary importance to most space agencies is the need to improve the status of the allocation of the space research, space operations, and earth exploration satellite services in the bands 2.025–2.110 GHz and 2.20–2.29 GHz.

Currently, footnotes to the Table of Frequency Allocations in Article 8 of the International Telecommunication Union's (ITU's) Radio Regulations authorize those services to use the 2-GHz bands, subject to coordination under the procedures detailed in the regulations' Articles 11 and 14. The procedures call for all satellite networks to "advance publish" mission information—including proposed launch date, frequency use, and orbital data—with the ITU's International Frequency Registration Board (IFRB). The information is distributed in an IFRB circular to all ITU member administrations for comment; the space agency must then coordinate mission details with any commenting administration.

Those conditions are imposed on the 2-GHz band to protect terrestrial fixed- and mobile-service systems using the same band.

> The world's space agencies generally agree on the spectrum requirements for communications links for scientific spacecraft into the next century

While that is a reasonable objective, it presents two major drawbacks to the space service users. First, as more and more spacecraft have made use of the bands over the last three decades, the resultant congestion has made the coordination process very lengthy and onerous to the space agencies and their parent governments. Second, because the allocation is made by a footnote to the allocation table, the space services' heavy use of the bands is not visible in the main body of the Table of Frequency Allocations, giving the impression that the bands are not being used.

The underlying technical reason for preferring the 2-GHz bands over some other bandwidth is that they provide highly reliable all-weather communication in which spacecraft can be controlled regardless of their orientation.

A large number of telecommunication administrations, including those of 23 nations in Europe, have proposed to WARC-92 that the 2-GHz allocations be upgraded to primary status—that is, protected from interference caused by any other services sharing the same band. In such a case, appropriate technical safeguards, such as power flux density limits at the earth's surface, would be implemented to continue to protect the terrestrial services.

SPACE-WALKING ASTRONAUTS. For manned exploration of the solar system to become a reality, the international Space Station Freedom must first be constructed. To assemble and maintain the station, astronauts will have to spend many hours outside the safety of the space shuttle, but in constant communication with it.

Ideally, radio frequencies of around 400 MHz would provide a reliable communication channel independent of the orientation of the space shuttle. At frequencies higher than about 500 MHz, the protective material of the astronaut's space suit reflects and blocks the rf signal. At frequencies lower than about 300 MHz, the size of the antenna required to produce an omnidirectional radiation pattern becomes unwieldy compared to the size of the suit.

In addition, because the available power for communications is very small compared with the power required for life-support systems, the transmitter housed in the space suit has a maximum power of about 250 mW, limiting the distance the astronaut can be separated from the shuttle to about 1 km.

The 400-MHz range is also being sought for a narrow-band voice and data communication channel between manned vehicles in orbit, such as the space shuttle and the Space Station Freedom during docking maneuvers.

DATA RELAY SATELLITES. As technology continues to provide more complex and sophisticated scientific instrumentation, greater demands are levied on satellite systems that would communicate that high-bandwidth

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The Space Frequency Coordination Group

Country	Organization	Headquarters	Responsibilities
National agencies			
Argentina	Comision Nacional de Investigaciones Espaciales (CNIE)	Buenos Aires	Space research and earth exploration programs
Australia	Australian Space Office (ASO)	Canberra	Space program management
	Commonwealth Scientific and Industrial Research Organization (CSIRO)	Canberra	Space program, scientific research, and astronomy observations
Austria	Austrian Space Agency (ASA)	Vienna	Space research and earth exploration programs
Belgium	Service de Programmation de la Politique Scientifique (SPPS)	Brussels	R&D for and management of space programs
Brazil	Instituto Nacional de Pesquisas Espaciais (INPE)	São José dos Campos	Space program development and management
Canada	Canadian Space Agency (CSA)	Ottawa	R&D for and management of space programs
People's Republic of China	Chinese Academy of Space Technology (CAST)	Beijing	Development and management of the space science programs
France	Centre National d'Etudes Spatiales (CNES)	Paris	Management of all facets of space programs
Germany	Deutsche Forschungsanstalt für Luft- und Raumfahrt eV (DLR)	Cologne	R&D for and operation of space program
India	Indian Space Research Organization (ISRO)	Bangalore	R&D for and management of space programs
Italy	Telespazio	Rome	Space commercialization, R&D within space program
Japan	Institute of Space and Astronautical Science	Sagamihara	Scientific research and space science research programs and development
	National Space Development Agency (Nasda)	Tokyo	Development, operation, and management of space programs
Spain	Instituto Nacional de Técnica Aeroespacial (INTA)	Madrid	R&D for and operation of space program
Sweden	Swedish Board for Space Activities (SBSA)	Solna	R&D for space programs
	Swedish Space Corp. (SSC)	Kiruna	Research and operations of space missions
United Kingdom	British National Space Center (BNSC)	Defford	R&D for and management of British space program
United States	Goddard Space Flight Center (GSFC)	Greenbelt, Md.	Launch operations and control management for NASA space programs
	Jet Propulsion Laboratory (JPL)	Pasadena, Calif.	Management and operation of unmanned solar system exploration program
	National Aeronautics and Space Administration (NASA)	Washington, D.C.	All facets of manned and unmanned civilian space programs
	National Oceanic and Atmospheric Administration (NOAA)	Washington, D.C.	Research into and operations and maintenance of earth exploration and meteorological satellite systems
Russia[a]	Institute of Space Device Engineering	Moscow	Provision of vehicles and launch support for space program
	Intercosmos Council	Moscow	Management and operations of space program resources
	Scientific Council for Radioastronomy	Moscow	Ground- and space-based radioastronomy observations
International consortia			
	International Coordination of Space Techniques for Geodesy and Geodynamics (CSTG)[b, c]	Austin, Texas[d]	Coordination of space observations required for geodetic and geodynamic measurements
	Comité Consultatif International des Radiocommunications (CCIR)[c]	Geneva	Establishment and maintenance of technical support for the international radio regulations
	Consultative Committee on Space Data Systems (CCSDS)[c]	Pasadena, Calif.	Establishment and maintenance of standards for space data systems
	European Organisation for the Exploitation of Meteorological Satellites (Eumetsat)	Darmstadt, Germany	Operations and management of European meteorological satellite systems
	European Space Agency (ESA)	Paris	Management of all facets of the European Community's joint space programs
	Inter-Union Commission on Frequency Allocations for Radio Astronomy and Space Science (Iucaf)[c]	Epping, N.S.W.,[e] Australia	Establishment and maintenance of adequate spectrum allocations for radio astronomy

Source: Robert M. Taylor

a At press time.

b Formally, Commission VIII of the International Association of Geodesy.

c These organizations have the status within the Space Frequency Coordination Group of observers—that is, they are not space agencies but have concerns that would affect or be affected by the space science services.

d Center for Space Research, University of Texas.

e B.J. Robinson, CSIRO, Division of Radiophysics.

NOTE: All these space agencies have agreed on what to do about most of the important issues facing the space science services (see main text), and their conclusions are being advanced to the 1992 World Administrative Radio Conference. In addition, some of the individual nations that are home to these agencies have formally submitted proposals for allocations to various space science services. All the members of the Space Frequency Coordination Group, which was founded in 1979, are civilian agencies mainly interested in space exploration and research. Some countries have more than one member because more than one agency has a distinctive space science responsibility.

data back to earth. A major driver for more bandwidth in the immediate future is the proposed Mission to Planet Earth—a comprehensive, multinational study of the global environment and its processes.

But before such projects can be made possible, the demand for higher-bandwidth spectrum allocations to support the transmission of data at rates up to 650 megabits per second must be satisfied. Japan and the United States have proposed allocating the 25.25–27.50-GHz band to the job of sending this data back to earth through a network of geostationary data relay satellites. Other countries may well support this proposal at WARC-92.

DEEP SPACE PROBES. The ITU definition of deep space is any distance greater than 2 million kilometers from the earth. Five times farther than the moon, that distance is a little beyond the Lagrangian distance where a body would be held in equilibrium by the gravitational fields of the earth and the sun.

Interplanetary probes into deep space must communicate with the earth in different frequency bands from spacecraft in earth orbit; otherwise, the weak signal levels (on the order of 2×10^{-19} W/m^2) from such distant spacecraft would be overwhelmed by the much higher signal levels (on the order of 3×10^{-14} W/m^2) from much closer spacecraft.

Currently, there are allocations to the space research service near 32 and 34 GHz that are limited to deep space—but only in Australia, Spain, and the United States. For many other countries, these space research allocations are not limited at all. The United States has proposed to WARC-92 that the deep-space limitation be applied to those frequencies worldwide. Generally, members of the Space Frequency Coordinating Group agree that this is a good idea, and Brazil has submitted a similar proposal.

To provide adequate spectrum for communications supporting the manned exploration of the solar system, new allocations are required at frequencies above 20 GHz. U.S. President George Bush's space exploration initiative is one example of such future missions; it calls for the establishment of a lunar colony beginning in the year 2001.

MARCHING ON MARS. Communication links for such exciting projects will require bandwidths of 500 MHz to be made available, without being restricted to deep-space use—in part so that equipment for Mars can be first tested on the moon. As the result of preliminary technical studies of available frequency bands between 20 and 40 GHz, NASA has suggested that the bands 37.0–37.5 GHz and 39.5–40.5 GHz would be most suitable for future planetary missions.

In addition, the former Soviet Academy of Space Science (IKI) has identified the requirement that allocations be made for communication links supporting radio astronomical observations known as very long baseline interferometry (VLBI). The academy envisions one or more radio telescopes located on the earth with others on one or more spacecraft thousands or tens of thousands of kilometers away, with the two far-flung sets of instruments simultaneously studying the detailed structure of the same quasi-stellar object (quasar).

The communication links for such radio telescopes would have to provide precisely phased timing information to the space platform, as well as wideband communication channels from the space platform to the earth. The bandwidths required are 1 GHz (between 20 and 40 GHz) and up to 10 GHz (above 40 GHz).

Russia has proposed the allocations 28.5–29.5 GHz and 74–84 GHz to satisfy these VLBI requirements. While supporting those proposals, the Space Frequency Coordination Group has considered another possibility—namely, that the space VLBI requirement between 20 and 40 GHz could well be satisfied by expanding the proposed allocation for the space research service at 37.0–37.5 GHz into a proposal for 37–38 GHz; this band would be used jointly for future planetary missions and space VLBI. The United States has submitted such a proposal to WARC-92.

Some nations view the Russian proposal for an allocation at 74–84 GHz for recovery of space VLBI data as premature, but the sharing conditions in this region of the spectrum are favorable. Thus, in the absence of any opposition, this allocation proposal may be approved.

EARTH EXPLORATION. Russia has also proposed that earth exploration satellite data be downlinked to the earth in the band 37.5–40.5 GHz. The Space Frequency Coordination Group generally agrees that such an allocation would be useful.

In addition, the group wishes to preserve certain frequencies for exploring the earth and its atmosphere. Certain elements and molecules in the earth's atmosphere strongly absorb microwave radiation at certain very narrow frequencies. Passive observations of some of those so-called absorption lines yield information about the temperature and other characteristics of the atmosphere vital to climatologists learning about the earth. Measurements of absorption lines, such as the frequency of 60.792 GHz absorbed by atmospheric oxygen, could be distorted if radiocommunication services were allowed to use the same frequencies.

Similarly, environmentalists want to acquire an allocation for passive observations at 149–151 GHz to protect microwave sensors observing atmospheric water vapor lines at 150 GHz.

In a nutshell, new or upgraded frequency allocations are required to support existing and planned space research, earth exploration satellite, space operation, and intersatellite activities in frequency bands ranging from 400 MHz to 151 GHz. Broad agreement on the underlying requirements and planned uses of those allocations has been reached by the members of the Space Frequency Coordination Group.

Opposition to these proposals at WARC-92 is expected in only a few cases. At 400 MHz, existing fixed- and mobile-service users must be convinced that adequate protection to their systems is afforded by the values of power flux density limits established in the report of the ITU's International Radio Consultative Committee (CCIR) to WARC-92.

At 2 GHz, the proposed terrestrial cellular elements of the future public land mobile telecommunication system (FPLMTS) could cause significant interference to space service operations because of the cumula-

A beacon for uplink power control

A number of new systems are beginning to explore the possibilities of satellite communications at frequencies of 20–30 GHz. However, a major problem in communicating at those frequencies via satelllite is that the signals are absorbed as they travel through rain or water vapor in the earth's atmosphere.

The attenuation increases exponentially with higher frequency. At 20 GHz or higher, rainfall can destroy tens of decibels in signal strength. Such varying attenuation must be overcome if communications systems at those frequencies are to be reliable and economically viable. Uplink power control is one method of countering the effects of rain fading.

At the 1992 World Administrative Radio Conference, the United States and other nations will propose establishing a frequency band for space-to-earth satellite beacon signals, which can be monitored by earth stations for attenuation. Then the station originating the signal could dynamically adjust the power of its uplink (earth to space) transmission to counter the atmospheric attenuation suffered at any given moment.

The Advanced Communications Technology Satellite (ACTS), which the U.S. National Aeronautics and Space Administration (NASA) has developed and has scheduled for launch in early 1993 to demonstrate satellite communications technologies in the 20- and 30-GHz bands, will operate a beacon at 27.505 GHz. The beacon's steady signal will be monitored by the ACTS control station at NASA's Lewis Research Center in Cleveland, Ohio, to test the feasibility of real-time uplink power control in mitigating rain attenuation.

The United States has proposed that uplink power control beacon frequencies be established within the 27.5–29.5-GHz portion of the spectrum, which is currently allocated to the fixed-satellite service for uplink use only. Since the beacon is a narrow-bandwidth downlink signal received by the uplink earth station, the beacon would not interfere with uplink fixed satellite service operations. Establishing a frequency band for uplink power control beacon signals is expected to benefit future systems in the 20–30-GHz band. *—Ann O. Heyward*

Multipurpose satellite allocations

Satellite communications technologies are at the stage today where fixed, mobile, and point-to-multipoint communications to ever smaller portable user terminals can be handled simultaneously and compatibly in the same frequency band from the same spacecraft. Integrating a full range of communications services onto one space platform means that a whole host of applications will become available to users for the price of one launch. Multipurpose communications capabilities using the portion of the spectrum from 20 to 30 GHz have been designed into a number of communications satellites now operating or scheduled for launch in the next few years.

Satellites with diverse capabilities are not always readily accommodated at the same frequencies under the International Telecommunication Union's (ITU's) existing definitions of satellite services and the relative status of their allocations. For example, at any one frequency, one service may be designated as primary (having priority) and the other as secondary (not allowed to interfere with the primary service). A system offering many services might then be limited by the level of interference protection available to providing a set of services that does not fully meet its users' needs.

Current regulations require that a provider coordinate a satellite system—that is, satisfy procedural requirements protecting other communications systems from interference—under specific service definitions. For multipurpose satellite systems, coordination can become complex. It may be a challenge to determine which service definition accurately accommodates a particular application. Alternatively, the limitations of the service definitions for a frequency band may prevent the use of a common satellite to provide several applications at that frequency. In that case, both satellite and user terminal design may be unduly complicated and expensive if services must be offered in different bands. All these limitations are due to regulations, not technology.

The 1992 World Administrative Radio Conference (WARC-92) will consider possible allocations of frequency bands above 20 GHz to a new service variously called the multipurpose satellite service or the general satellite service. Creation of the service could simplify the process of implementing multipurpose satellite networks.

International support for the creation of such a service is substantial. Exact frequencies to be allocated are still being debated because their selection must be based upon a variety of technical and regulatory considerations. In addition, WARC-92 must determine which bands offer the best possibilities of sharing with existing service applications.

The move toward multipurpose satellites in the 20–30-GHz bands has been under way for many years in several countries. In the United States, the National Aeronautics and Space Administration (NASA) is developing the Advanced Communications Technology Satellite (ACTS), which, after its 1993 launch, will operate at those bands, offering experimental fixed, mobile, and point-to-multipoint applications.

At least one U.S. company, Norris Satellite Communications Inc., Red Lion, Pa., has proposed to construct, launch, and operate a multipurpose satellite that would exploit the technologies being developed by ACTS to provide commercial fixed, mobile, and point-to-multipoint applications at the same bands. The U.S. Federal Communications Commission supported the creation of a general satellite service for systems of this kind, which in part led to the U.S. proposal to WARC-92.

Japan's CS-3, launched in 1988, and ETS-VI spacecraft, set for launch this coming August, are designed to explore satellite communications capabilities at 19 GHz (downlink)/28 GHz (uplink) and 20 GHz (downlink)/40 GHz (uplink), respectively. In Europe, the Olympus spacecraft of the European Space Agency and the Italsat satellite of the Italian Space Agency were developed to explore communications applications at 19/29 GHz and 20/40 GHz, respectively. Several countries in ITU's Region 2 (North, Central, and South America, and the Caribbean) have expressed support for the definition of a new multipurpose satellite service within the 20–30-GHz portion of the spectrum.

In effect, a general or multipurpose satellite service is emerging in the 20–30-GHz frequency bands around the world. At WARC-92, nations will have the opportunity to discuss its formalization.

—Ann O. Heyward

tive noise from the anticipated high density of subscribers [see "Mobile telecommunications," pp. 27–29].

This issue has been addressed in several CCIR study groups and working parties preparing for the coming conference. The conclusion: that sharing between these systems is not feasible. However, spectrum between 1 and 3 GHz must be identified at WARC-92 to satisfy FPLMTS requirements, adding to the competition for frequency allocations in this range.

The remaining space service proposals, although not expecting strong opposition, will not be a cakewalk. Many regulatory and technical issues must be resolved in Torremolinos before allocation proposals will be approved.

TO PROBE FURTHER. The fundamental document outlining the technical issues surrounding the 1992 World Administrative Radio Conference is the "Technical and Operational Bases for the World Administrative Radio Conference 1992 (WARC-92)," published by the ITU's International Radio Consultative Committee (CCIR), Geneva, 1991. It is available from the General Secretariat, Sales Section, International Telecommunication Union, Place des Nations, CH-1211, Geneva 20, Switzerland. The document that will be revised as a result of WARC-92 is the three-volume *Radio Regulations*, 1990, published by the ITU in Geneva.

The most authoritative document about the ITU itself is the International Telecommunication Convention, 1982, published by the ITU's General Secretariat in Geneva. It is reprinted in Gerd D. Wallenstein's *International Telecommunications Agreements* (Oceana Publications, Dobbs Ferry, N.Y., 1986).

A succinct background paper on the major issues of WARC-92—particularly those facing the U.S. government—is *The 1992 World Administrative Radio Conference: Issues for U.S. International Spectrum Policy,* prepared by the Office of Technology Assessment, U.S. Government Printing Office, November 1991. The 134-page document, OTA-BP-TCT-76, is available for US $6.50 from the Superintendent of Documents, Mail Stop SSOP, Washington, D.C. 20402-9328.

The concerns of amateur radio operators are summarized in "WARC-92: What it Means to You," by Kirk Kleinschmidt and Paul Rinaldo, *QST* magazine, June 1991, pp. 16–18 and p. 64.

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Reinhart, Taylor, and Heyward have all been selected to participate as U.S. delegates to WARC-92.

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Testability on TAP

Testing loaded digital logic boards becomes much easier with a standard test access port, or TAP, meant for boundary-scan tests

Late in 1985, a number of test engineers representing major European electronics companies met in Eindhoven, the Netherlands. Their concern: the declining effectiveness and rising cost of testing loaded digital printed-circuit boards by probing them physically. The revolution started by what would eventually become the Joint Test Action Group (JTAG)—and still gathering momentum—enables loaded digital logic boards to be tested without being probed.

The new approach in testing is based on boundary-scan. This technique gives access to individual chip pins by including a little standardized circuitry on every IC. What is revolutionary here is not boundary-scan itself (which has been used for years by some manufacturers of large mainframe computers) but the development of a standard for it, and the acceptance of that standard by many manufacturers of ICs, test equipment, and design automation tools around the world.

Today, just over five years after that meeting, the required standard—ANSI/IEEE Std 1149.1—has been established, and the first products to support it are on the market. These early arrivals foreshadow ■ wide spectrum of ICs, tools, and techniques that could transform the way all types of testing are performed, from design debugging, through manufacturing and systems test, on into field service.

To appreciate how far boundary-scan has come and to assess its prospects, it is helpful to review why it is needed before explaining what it entails.

SMALLER AND DENSER. Conventional methods for testing loaded circuit boards have become steadily less effective as ICs have both shrunk in size and grown more complex. Test techniques that became popular in the 1980s—notably in-circuit testing—depend on the ability to make contact with connections internal to the loaded board. The most common means of doing so are bed-of-nails fixtures and hand held diagnostic probes. But the use of surface-mounted devices, particularly when coupled with double-sided component mounting and buried vias, turns probing the finished product into an obstacle course, at the very least.

Colin M. Maunder BT Laboratories
Rodham E. Tulloss AT&T Bell Laboratories

Moreover, the greater the complexity of ICs, the harder it becomes to generate tests that will exercise them fully from the board edge, as functional testers do. Test data must propagate through a number of complex chips to reach those at the heart of the product, so that very much longer test sequences are needed. Consequently, the time needed both to generate and execute those sequences has risen sharply, boosting the cost of testing.

Similar trends are evident in the ICs themselves and the systems into which the loaded boards are assembled—ever larger amounts of circuitry must be tested through a more or less constant number of external interfaces.

Manufacturers have responded to these problems by building some parts of the test equipment into the circuit itself in systems and also, increasingly, in loaded boards and ICs. The built-in test equipment (BITE) is directly attached to complex building blocks deep within the circuit, but is controlled remotely from an external test processor, to coordinate tests applied using BITE and external test equipment.

> What is revolutionary is that a standard was developed for boundary-scan test and IC makers were quick to accept it

In some cases, enough test capability can be built into the circuit for ■ test to be performed in response to a simple GO instruction from the external processor. This technique is called built-in self-test (BIST).

BOUNDARY-SCAN BASICS. Boundary-scan is ■ built-in technique for testing ■ loaded printed-circuit board—specifically, the digital ICs and their interconnections. Its key feature is the insertion in every IC of small quantities of logic, called boundary-scan cells, between each pin and the chip circuitry to which that pin normally is directly connected [Fig. 1]. In addition to their connections to the package pins and the working logic, the boundary-scan cells have other terminals through which they can be connected to each other, forming a shift-register path around the periphery of the IC.

During normal operation, data is passed between pins and logic as if the boundary-scan cells were not there. When put into the test mode, however, they can be directed by a test program to pass data along the shift-register path, which need not be confined to a single chip, but can encompass the entire board. Once data has been loaded into the cells, it can be used instead of the data flowing to or from the pins, so that either the internal logic or the external chip-to-chip connections can be tested. Boundary-scan thus can put desired test sequences wherever they are needed. It also makes it easy to distinguish testing the chips themselves from testing the connections between chips.

The formal name for the new standard is ANSI/IEEE Std 1149.1, *IEEE Standard Test Access Port and Boundary-Scan Architecture*. It defines a number of "tools" that may be built into ICs to assist in the testing of loaded boards and other assemblies, and it gives details on how the tool set can be expanded to meet the needs of a particular chip design. The standard also defines ■ method of communicating test instructions and data from an external test processor to the various ICs on a board so the right combination of tools can be configured and

Defining terms

Boundary-scan: a technique for providing electronic access to the input and output pins of an IC through incorporation of a shift-register path between each pin and the logic inside the chip.

Emulation test: a test technique for loaded boards in which the on-board microprocessor is disabled while its function is emulated by the test system.

Functional test: a test process that relies primarily on stimulating ■ loaded board through its connector and observing its normal outputs. During fault diagnosis, handheld guided probes may be used to gain access to internal signals on the board under test.

In-circuit test: a test technique for loaded boards that requires contact to every internal signal connection. That contact is provided by a bed-of-nails test fixture.

used at each successive stage of testing.

Four or five extra pins, over and above the normal pins with their added boundary-scan cells, are found on an IC that complies with the new ANSI/IEEE standard. These pins constitute the test access port, or TAP. The TAP is analogous to the diagnostic socket found on many automobiles: it allows an external test processor to control and communicate with the test features built into the product.

Of the TAP pins, two (test data in, TDI; and test data out, TDO) provide for the serial input and output of data, while the others control the movement and use of data in accordance with a defined protocol. The protocol is interpreted by a small finite-state machine (the TAP controller) that generates the control signals required to operate the test tools built into each IC. Those control signals—Update, Mode, and Shift/Load*—determine such matters as whether the boundary-scan cell should be in its normal mode or test mode (the asterisk on some signals indicates that they are active when at a logic zero level).

The TAPs of individual ICs on a loaded board can be configured in various ways. In Fig. 1 at top, they are connected to provide a single ''daisy-chain'' serial data path that snakes its way around the board. Building that single serial path is simple: the TDO of one chip is connected to the TDI of the next chip in the chain. Note that, in the Fig. 1 example, the control signals are not daisy chained but broadcast in parallel to all boundary-scan ICs. Those control signals are the Test Clock (TCK), Test Mode Select input (TMS), and, optionally, Test Reset input (TRST*).

The boundary-scan register is the principal tool defined by the standard. It consists of a chain of shift-register–based cells around the periphery of an IC as described earlier [Fig. 1, right].

THREE TEST TYPES. Three principal types of tests can be performed with the boundary-scan register. They are: interconnect tests, using the EXTEST (external test) instruction; chip tests, using the INTEST instruction; and sampling, using the SAMPLE instruction [Fig. 2].

The interconnect test is invoked by entering the EXTEST instruction into the chips at each terminal of a set of interconnections. Test patterns are then shifted into the boundary-scan cells at chip output pins and driven onto the board-level interconnections by setting their Mode inputs to 1. The responses that arrive at chip inputs are loaded into their boundary-scan cells (while Shift/Load* is 0) and shifted out for examination (while Shift/Load* is 1). By careful selection of the applied test patterns, it is possible to test chip-to-chip connections for stuck-at, short-circuit, open-circuit, and other fault types.

Suppose, for instance, a circuit contains a short-to-ground (stuck-at-0) fault and a wired-OR short-circuit fault in the chip-to-chip connections [Fig. 2, left]. To look for these faults, the EXTEST instruction must be selected and two test patterns applied. Each is shifted into the boundary-scan registers separately, with the rightmost bit of the pattern being shifted in first. The expected responses, which would be shifted out as the next test pattern is shifted in, differ from the actual responses that indicate the presence of the faults. In either case, the rightmost bit would be shifted out first.

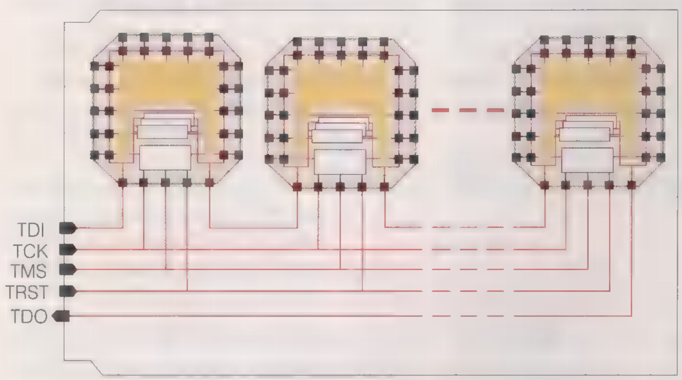
The INTEST instruction allows a low-speed test to be applied to chips on a board by, for example, single-stepping them through their paces. (Complex chips, of course,are more efficiently tested through use of on-chip BIST, accessed and controlled through the standardized boundary-scan test circuitry.)

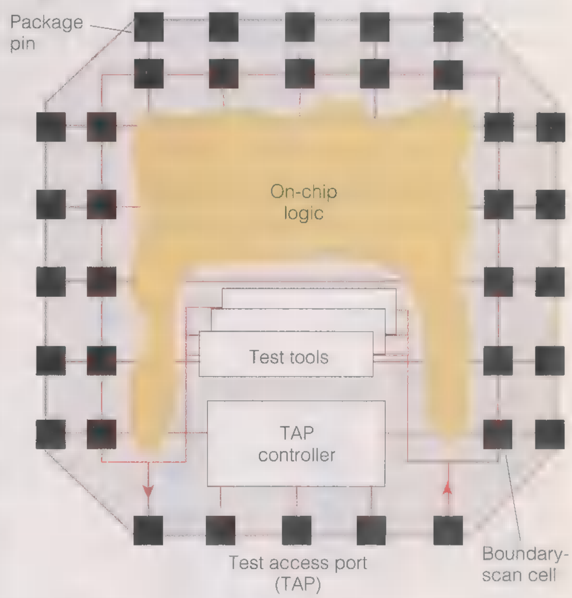
When the INTEST instruction is selected, the Mode control signals for the boundary-scan cells at input pins are set to 1. Test vectors are shifted into the boundary-scan register and applied to the circuitry within the IC [Fig. 2, middle, where it is represented as a single NAND gate]. The test result is then loaded into the cell at the output pin (Shift/Load* 0) and shifted out for examination (Shift/Load* 1).

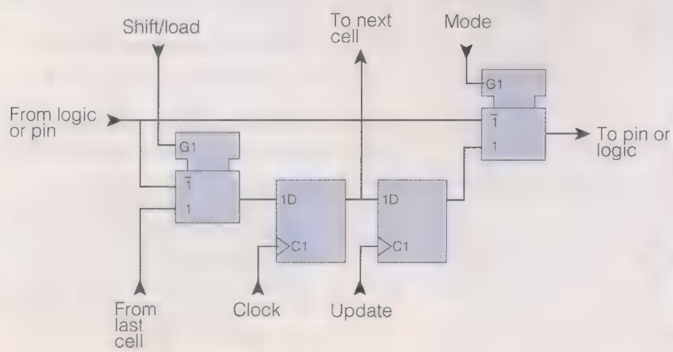
The SAMPLE instruction can be used during design debugging or walk-back guided probing (for example, during functional or system test). When this instruction is selected, it holds the Mode inputs of all cells in the IC at 0, so that signals flow directly between the package pins and the on-chip logic. Thus, the chip is free to perform its intended function normally.

While normal, non-test operation is in progress, the boundary-scan register can take snapshots of the signals flowing into and out of the chip [Fig. 2, right]. By cycling the operation of the loaded board or system and taking a succession of snapshots, it is possible to build up a picture of the operation of the circuit from the data shifted out of the boundary-scan register.

DEVICE ID. It is sometimes necessary to identify the source, type, and version of an IC during testing. For instance, the wrong version of an IC may have been used or a







[1] When loaded onto a printed-circuit board, components that conform to the boundary-scan standard can be daisy chained so that all of the circuitry on the board is testable from the edge connector (top left). What makes that possible are the chips' test access ports (TAPs) and the boundary-scan cells inserted on every chip between each of its pins and its internal logic (above). Each boundary-scan cell (bottom left) is connected to the adjacent boundary-scan cells as well as to the chip logic and an I/O pin.

second-source component that is not totally compatible with the original, or application-specific ICs with radically different functions but identical package styles may have been mixed up.

To assist with these problems, the standard specifies a device identification register that can be included in a chip design. In response to the IDCODE (identity code) instruction, this register loads 32 bits of data that identify the chip manufacturer and chip type and version in a defined format. This data is then shifted out of the circuit for examination.

BYPASS REGISTER. The bypass register is, in effect, a null tool that can be selected when no other test operation is required in a given IC. Selecting the bypass register with the BYPASS instruction allows the normal operation of the IC to continue without interference. It speeds the flow of test data through the IC by reducing to one clock cycle the number of clock transitions required to move data from the serial input to the serial output.

The BYPASS instruction is particularly useful when a few complex chips are to be tested on a board containing many other ICs that meet the standard. In that case, the BYPASS instruction can be scanned into all ICs other than those that will undergo test, while the target ICs receive the instructions appropriate to initiating the required tests.

Built-in self-test, BIST, the highly effective way of testing complex circuits, is encouraged by the new standard special instruction, RUNBIST. RUNBIST can be fed to an IC to trigger self-test execution in a uniform way, independent of the details of the test.

Before publication of the standard, there was no uniform way to access the BIST features of ICs once they had been assembled onto a board. For example, execution of the self-test might have required application of idiosyncratic sequences at the chip inputs or careful monitoring of the outputs. Consequently, in most cases, the addition of BIST had to be justified solely in terms of its benefit to the IC manufacturer.

By combining BIST and boundary-scan, on-chip BIST can be made available to all users of an IC and accessed at both the loaded-board and system levels. The benefit to such users would readily offset an increase in the cost of the ICs themselves. For one thing, much less need be developed in the way of system-level diagnostics when boundary-scan and BIST are provided in ICs and made accessible at the system level. A study performed by AT&T Bell Laboratories, Murray Hill, N.J., for a small private branch exchange (PBX) system showed a two-thirds reduction in the time taken to develop system diagnostic software. A further indication of user interest in self-test is evident from recent Department of Defense (DOD) requirements for complex digital systems, which must guarantee their readiness by completing a high-quality self-test within tens of seconds of power-up.

CUSTOMIZATION. A key goal of the standard's developers was that it should be extendable to meet a particular IC's requirements, provided certain basic rules are met. A number of IC makers are already taking this opportunity to supply test- and design-support tools specific to their ICs.

Two types of design-specific tool are possible: public tools, for component users, and private tools, for just the IC manufacturer. Instructions relating to private tools would be clearly identified as "not for customer use" in product documentation, while public-tool instructions would be fully documented.

The IC designer may take advantage of the extendability of the standard to provide more test-support tools with corresponding instructions—say, offering the component user a range of self-tests that go beyond the RUNBIST instruction. For example, quick tests could be supplied for use at power-up or in certain field service environments; alternatively, detailed, more time-consuming tests could be provided to exercise parts of the IC in depth.

The designer may even make non-test support tools accessible through the TAP. The 320C50 digital signal processor (DSP) from Texas Instruments Inc., Dallas, for example, provides the circuitry mandated by the standard and offers support for in-circuit emulation through an extended instruction set. The extra instructions give the user access to internal registers on the chip. Thus, two support requirements—test and firmware debugging—are supported through a common interface (the TAP). Other vendors of DSP ICs, most notably AT&T, are taking a similar approach, and standards may eventually evolve in this area.

Elsewhere, manufacturers are developing electrically alterable memories that can be reprogrammed through their TAPs, without removal from the board.

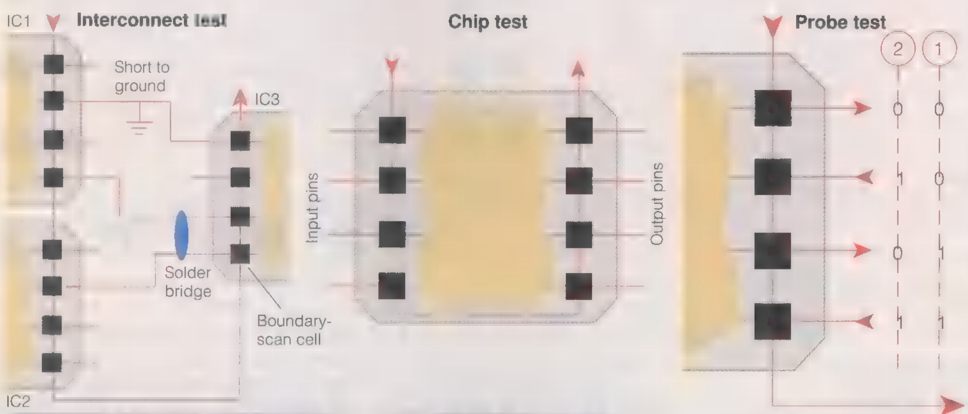
INSTRUMENT ON A CHIP. In the longer term, the standard could serve as the basis for embedded instrumentation—instrumentation integrated onto a chip, which in turn could be built into a loaded board or system to facilitate observation or control of its behavior. Of most value in that application would be the standard's provision of a uniform framework for moving instructions and test data. The standard delivers the equivalent of the IEEE Std 488's capability for rack-and-stack instrumentation.

Silicon instruments will especially benefit highly miniaturized systems—for example, those that have to be immersed in coolant when powered up. Applications also exist in less sophisticated systems. For example, intermittent problems can be elusive; after all, Murphy's Law dictates that they will rarely occur when the field technician is on site. In such cases, very low-cost instrumentation, based on ICs like TI's, could be installed in a working system; then, whenever a fault occurred, they could send the history of the events preceding it to a remote service center.

Given all these examples and possibilities, what do they imply about the nature of testers in the future? One thing is certain: there will be changes, and those changes will be dramatic.

Of course, in the beginning, some of the components on a board will conform to the standard and some will not. Most manufacturers of test equipment have indicated that during that transitional period, they will respond to the standard with software upgrades to their existing products. That will leave the test engineers in a familiar environment during the transitional period.

Eventually (rather quickly in some companies), use of the standard will be fully combined with BIST. Then testers could



Input	Output (expected)	(actual)
x1x1xoxxxxxx	xxxxxxxx01x1	xxxxxxxx11x0
x0x0x1xxxxxx	xxxxxxxx10x0	xxxxxxxx11x0

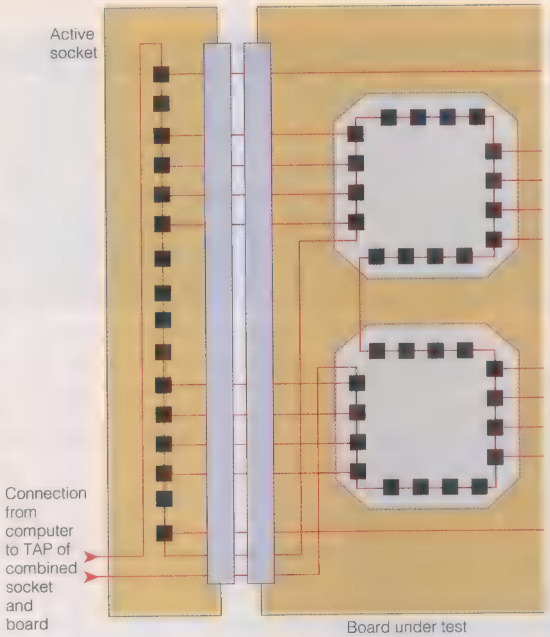
Input	Expected output
x10xxxxx	xxxxx1xx
x01xxxxx	xxxxx1xx
x11xxxxx	xxxxx0xx

[2] The boundary-scan register facilitates testing the interconnections between chips (left) and the chips themselves (middle). It also helps in grabbing "snapshots" of pin activity (right).

well be no more than a small computer (perhaps a PC) equipped with appropriate software and, in some cases, a hardware plug-in to provide programmable clocks and a means of addressing the TAP. Alternatively, the PC's parallel I/O port can be used as a low-throughput connection to a board's TAP.

Testers of these kinds are already available from several companies—for example, AT&T, Texas Instruments, Alpine Image Systems, Los Altos, Calif., and Carl Zeiss, Oberkochen, Germany—offer an early glimpse of the future.

Testing of off-board connections can be achieved through an "active socket" consisting of a number of boundary-scan cells connected to form a shift-register–based path that visits each connector pin [Fig. 3]. Such sockets would appear to the PC-based tester as an additional boundary-scan component appended to the loaded-board's serial daisy chain. They could be constructed as molded modules—one per connector type—and programmed through their TAP to match the input/output configuration of the particular board.



[3] Although it can test all of the components on a board, boundary-scan circuitry cannot test a board's connections to the outside world. That gap may be bridged by an "active socket" consisting of a number of boundary-scan cells connected to form a shift-register–based path touching every connector pin.

Through use of ANSI/IEEE Std 1149.1, a structured approach can be taken to the testing of loaded boards. With such an approach, it will be possible to reuse test data created for individual ICs—for example, their post-manufacturing tests or a self-test procedure. Test development for the loaded board involves assembly of this pre-existing data and test pattern generation targeted at the "new" circuitry introduced when the board is assembled—the chip-to-chip interconnections and the circuitry that does not conform to the standard.

Test equipment for testing individual ICs can be expected to undergo similar changes. In the long term, widespread use of boundary-scan and BIST will allow powerful and expensive automatic test equipment to be replaced by much simpler, lower-cost test systems. Already, one supplier (Schlumberger Technologies, Mountrouge, France) has developed a test system for ICs that use serial built-in test techniques, such as boundary-scan. Here, the chief advantage of built-in testing is that most connections between test system and the IC can be exercised at low speeds—say, a few megahertz—reducing the amount of expensive, high-performance test circuitry required in an ATE.

SYSTEM TESTING. As with boards, assembled systems can accept a structured test based on boundary-scan. Here, the pre-existing test data for the various boards is brought together and supplemented with tests for new system-level features, such as board-to-board connections. Work on a standard to facilitate such an approach is well advanced. This draft standard—currently named IEEE P1149.5, *Module Test and Maintenance Bus*—will define a uniform method of communicating test, maintenance, and other support information between a system-level test processor and a module-level controller (the equivalent of the TAP). The system-level test processor may be built in, in which case it could be accessed remotely over the phone network, or it could be a PC-based tool of the kind described earlier.

With the advent of boundary-scan and powerful portable notebook and laptop PCs, it will once again become possible to equip field technicians with testers of similar fault-finding capability to those used in the manufacturing environment. The value of such highly portable tools in field service could be enormous.

ACCEPTANCE. One pleasure about working on ANSI/IEEE Std 1149.1 has been the speed with which the standard has been picked up and put to work. The room for innovation allowed by the expandable instruction register and instruction set has made it possible for both test and other features of ICs to be activated through the TAP. The positive experiences of designers and customers with the first generation of ICs that conform to the standard, and with the growing set of hardware and software tools, has been striking.

ATE manufacturers such as GenRad, Schlumberger, Teradyne, and Hewlett-Packard are assigning lead researchers to the expected revolution in testing. They believe the first ripples of change are already behind them, and expect the first sizeable wave within this next year.

Among IC vendors, Analog Devices, AT&T, and Texas Instruments have announced digital signal processors with boundary-scan. Leading-edge microprocessors have been announced by Intel, Motorola, National Semiconductor, and MIPS Computer Systems. National Semiconductor Corp., Santa Clara, Calif., and Texas Instruments Inc., Dallas, also offer standard logic parts with boundary-scan, which can aid in testing boards using components that do not support the standard.

TO PROBE FURTHER. ANSI/IEEE Std 1149.1, *IEEE Standard Test Access Port and Boundary-Scan Architecture* (SH 13144), is the formal document that defines the new boundary-scan standard. It is available for $49 from the IEEE Service Center, Box 1331, 445 Hoes Lane, Piscataway, N.J. 08855-1331; 1-800-678-IEEE. The center also provides an introduction to the standard in the form of a tutorial book consisting of specially written papers and selected reprints. *The Test Access Port and Boundary-Scan Architecture* (C.M. Maunder and R.E. Tulloss) is published by the IEEE Computer Society Press, Los Alamitos, Calif.; 714-821-8380.

Further material may be found in the proceedings of the major conferences on test technology such as the International Test Conference and the European Test Conference, and in many of the trade journals of the electronics industry.

IEEE Design and Test magazine has been selected as the journal of record by the IEEE 1149.1 Working Group.

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He is currently the chair of the IEEE P1149.1 Working Group and a member of the IEEE Computer Society's Testability Bus Standards Steering Committee. He received the 1991 Fluke Test Engineer Award for his contribution to 1149.1. A prize-winning poet, he is also a recognized expert on fungi of the genus *Amanita*. ◆

Digital storage scopes advance

Color display and data storage techniques make for more meaningful signal views and complex statistical measurements

The leap from analog to digital oscilloscopes eliminated information about waveform stability, made evident by the varying intensity of traces on an analog scope display. Now the loss has been more than made good by techniques newly developed for the digital storage oscilloscope (DSO). These represent waveform stability by color-grading the relative frequencies with which waveform points occur, and displaying the different frequency ranges in different colors.

Further, the statistical data from which such a display is generated can be used for really difficult quantitative tasks. These include histogram analysis, testing to within set limits, and automatic measurements using statistical techniques.

In analog oscilloscopes, any cycle of a repetitive signal traced on the phosphor of the cathode-ray tube (CRT) will fade over time unless the signal is retraced identically. This waning persistence reveals how often the signal traces the same or different paths. Parameters that could be observed (but not easily measured quantitatively) include vertical (voltage or current) noise, horizontal jitter, and trigger instability.

Some high-performance analog oscilloscopes do allow the user to control how long the waveform remains on the CRT before being erased [Fig. 1, top leftmost]. The feature was developed for viewing one-time, single-shot signals and infrequent events, but it cannot be calibrated and is adjustable over only a limited period of time. A further complication is the tendency for the trace to fade or bloom as intensity adjustments are made.

DIGITAL PERSISTENCE. Early DSOs solved the fading or blooming problems by refreshing displays with a digitized version of the signal stored in RAM. But in the process they lost information concerning signal persistence and hence signal stability.

Thomas A. Dye and Erik Teose Tektronix Inc.

Today's DSO techniques for displaying signals with variable and infinite persistence emulate analog phosphor performance to a degree. In digital scopes, variable persistence allows the signal trace's duration to be precisely adjusted, making the feature even more usable than in analog scopes.

TIME AGING. The most common variable-persistence technique used in DSOs is called time aging [Fig. 1, top center left]. With time aging, each acquired point of a waveform is represented on the screen by one pixel, or dot, of constant intensity. The dot remains until the persistence time set by the user is reached, and then is "aged," that is, erased from the display.

A more recent variable-persistence technique, called intensity grading [Fig. 1, top center right], is based on a modified time-aging technique employing several intensity levels (up to 16). Sets of pixels acquired during one sweep grow steadily dimmer until they vanish at the end of their allotted span, instead of suddenly going from maximum to zero intensity at that point. In essence, waveforms that occur less frequently (due to some form of signal instability) are acquired less often and therefore appear dimmer. Only the display is improved, however; because the technique is implemented with the time-aging approach, no quantitative measurements can be made from the variable-persistence data.

> Color grading is like infinite persistence with a colorized version of intensity grading thrown in

Infinite persistence [Fig. 1, top rightmost] is an extension of variable-persistence techniques. In general, it accumulates waveforms on the DSO display indefinitely, displaying every acquired pixel with the same intensity. It reveals gross signal characteristics, such as long-term drift or worst-case jitter, and captures rare events such as a metastable state. But like intensity grading, the technique is generally a display function only—it provides no quantitative measurement capability.

Color grading is like infinite persistence with a colorized version of intensity grading thrown in. The process allows waveform points to accumulate indefinitely on the display, with the user deciding when the screen should be cleared. The waveform thus displayed is analogous to a topographical map where different colors indicate different altitude ranges (or "number of points," in the case of the waveform) [Fig. 1, bottom right].

The means used to implement color grading, moreover, vastly enhances quantitative data measurement and analysis. Internal digital circuitry and software create a statistical database that accumulates thousands of repetitions of a waveform from which the color-graded display is generated. The microprocessor, RAM, and software mimic a two-dimensional array of counters [Fig. 1, bottom half]. Each "counter" in the "array" represents a pixel (or time/voltage coordinate) on the display and is incremented when a waveform sample falls on that pixel.

The process is simple enough. Each time

Defining terms

Bloom: the tendency of a waveform display to spread over a CRT in time, producing a large, distorted view of the waveform.

Eye diagram: an oscilloscope display resembling an eye, formed by acquiring a random data stream with the oscilloscope triggered by the data stream's synchronous clock. Also referred to as an eye pattern.

Histogram: a graphical (bar chart) representation of probability distributions.

Mask: a graphical drawing, typically some polygon, used in inclusive or exclusive limit testing.

Measurement statistics: statistics, such as mean and standard deviation, determined by examining a set of measurements. Each measurement in the set is computed from raw waveform data.

Metastability: the tendency of bistable devices, such as flip-flops, to enter a quasistable state from which the final output state is uncertain.

Statistical measurements: measurements computed directly by examining a large set of raw waveform data to determine statistical concentrations (that is, histograms).

Persistence, infinite: a display mode in which waveform points accumulate indefinitely on the display screen, usually with all waveform points of the same color or brightness.

Persistence, variable: a display mode that allows control of how long waveform information remains on the display screen before being erased.

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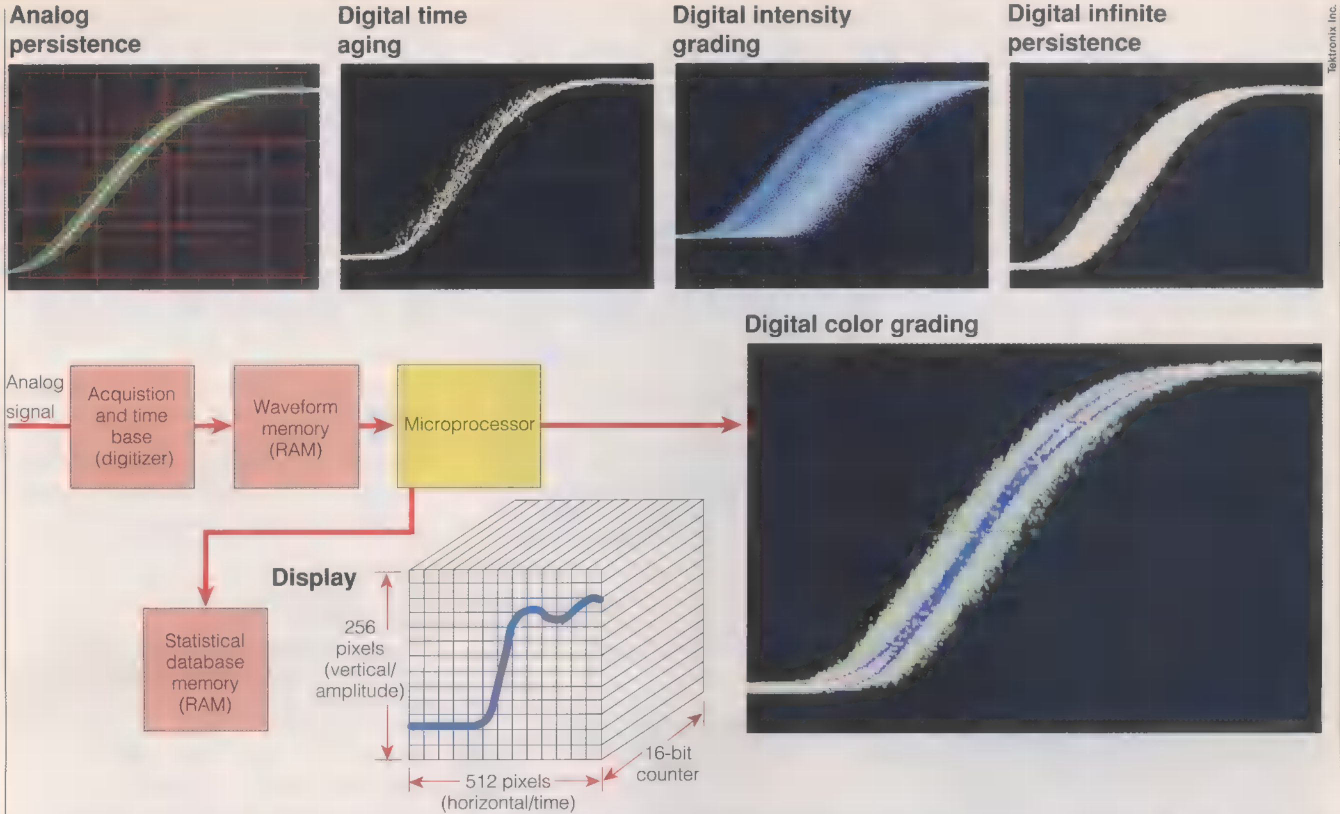


[1] Analog scopes with variable persistence (top leftmost) provided intensity information that could be used to spot jitter and random noise, but had fading or blooming problems. Digital scopes with time aging (top center, left) solved fading and blooming problems, but lost intensity data. Newer techniques include intensity grading (top center, right), infinite persistence (top rightmost), and color grading (bottom right). Used to produce a color-graded display, special software, along with a microprocessor and memory (bottom left), create a statistical database that keeps a count of how many samples fall on each pixel of the display. In effect, the database is a two-dimensional array of counters (bottom center); each counter in the array is associated with a pixel on the display.

the waveform is sampled (horizontal time axis), its amplitude (vertical axis) is scaled into a range of 1–256. The sample time and amplitude value form the column and row addresses, respectively, of a location in the 16-bit-wide statistical database memory. Any count stored in that location is checked to see if incrementing it will cause an overflow (resetting the value to all 0s).

All the values in the database are kept at maximum count if that count has been reached. Otherwise, the count for that address is incremented.

Visually, this stored data is used to add a third dimension to the display. Color acts like a z axis, indicating the density of events at various horizontal and vertical locations. Different colors are assigned to different ranges of count values in the database.

This assignment of colors to ranges of count values is based on the maximum count value residing in the database at the time the display is updated. At every update, in other words, the maximum database count and the color boundaries are recalculated. Consequently, the display reflects the statistical database as it changes over time.

CONS AND CURES. A few drawbacks to the color-graded technique should be noted. First, because the database "counters" are of finite size and stay at maximum once they reach it, the database and display will wash out after a long period of time, when all values reach maximum and are graded with the same color.

Fortunately, this would take several hours to happen, even for an extremely well-behaved and stable signal. A simple way to prevent such an occurrence is to use a "stop on maximum count" capability, which would halt acquisition as soon as a single database counter filled up.

Second, in extreme cases, the waveforms of interest may be displayed in fewer colors than is desirable for a detailed analysis. Normally, all acquired waveforms are accumulated into one database, and if any of them have quite different stabilities (that is, vertical or horizontal dispersions) from the waveforms of interest, these last may have their colors skewed toward either end of the color-grading spectrum.

Several color-graded DSOs solve this problem by enabling the waveform area of the screen to be split in two, the division being based on user-defined waveform criteria, such as stability. Each area has its own underlying database (although at half the vertical resolution) and each waveform area can be color graded individually.

An inconvenience of color grading is the slowness with which the display is periodically updated. The DSO software that converts the many count values into colors can take up to 2 seconds at each update to paint the whole screen.

POWER OF STATISTICS. While subjectively meaningful, the color-graded display is a less important application of the underlying statistical database than detailed quantitative analyses of the signal within the instrument itself.

One such use is the computation and display of histograms. Histograms are bar charts of the distribution of samples in a statistical population, that is, a data set. They can be useful in measuring random vertical (say, voltage) and horizontal (timing) phenomena in signals. Noise, for instance, can be measured using a vertical histogram, while jitter can be measured using a horizontal histogram.

The resulting histogram statistics, such as mean (m), peak-to-peak (Pk-Pk), and standard deviation (rms Δ, or σ), accurately quantify these useful signal characteristics. It becomes possible not only to measure how much noise or jitter is in a signal, but also to pin down the nature or source of the noise; the latter is indicated by the histogram distribution (as given by the percentage of samples contained within one, two, and three standard deviations around the mean) and shape.

Random noise generally produces the normal, bell-shaped (Gaussian) distribution,

whereas a nonrandom source, such as cross talk from ■ asynchronous signal, often generates ■ bimodal or other non-Gaussian distribution that is readily apparent. The nonrandom noise source may also be apparent in the color-graded display from the density (frequency of occurrence) information.

The statistical database may also be used for an automatic and quantitative measure of test conformance—an improvement on cutting masks out of paper and pasting them to the oscilloscope screen or drawing masks on the screen with a grease pencil. In tolerance and pass/fail testing with a statistical database, regions that correspond to desired specifications or standards are outlined electronically on the display. Once these have been masked off, the instrument makes use of the database to calculate how many samples fall in each masked area. As samples are added to the database, each mask count is updated.

One useful application of the combination of statistical database with mask testing is in analyzing metastability in digital circuits. The output of a flip-flop, for example, can be compared to a mask (or set of masks) of acceptable tolerances for ■ large number of acquired waveforms. This technique can reveal statistical information about how often the flip-flop's failure to adopt either one of two stable states occurs, and can also help to analyze the nature of the metastability.

TIME SAVINGS. When the user must make multiple measurements for, say, vertical and horizontal histograms, the statistical database lets it be done on the same set of waveform data. Previous methods required the user to acquire a new set of waveforms if the histogram type or limits needed to be changed. Because it often takes minutes or hours to satisfy statistical criteria in a waveform region in order to make ■ valid measurement, the statistical database can save the user a lot of time.

Masks, too, can be changed—edited or completely redrawn—and new counts automatically generated from one and the same set of waveform data in the database. The user also may switch back and forth between histogram analysis and mask testing, again without re-acquiring waveform data.

Designers and manufacturers using IEEE-488 or RS-232-C instrument interfaces can even transfer the statistical database to a computer for data logging or in-depth analysis. Such users can then retrieve selective waveform areas of importance to their test algorithms.

Perhaps the strongest attraction of the statistical database, though, is that it allows the use of statistical measurement algorithms, as opposed to simply computing statistics on measurements.

Many modern DSOs continuously measure and display the instantaneous values of waveform measurements, and then calculate and display certain statistics about them. For example, the instrument may keep a history of its instantaneous measurements of the rise time of a pulse, and then display that history's mean and standard deviation. Both these characteristics are measurement statistics.

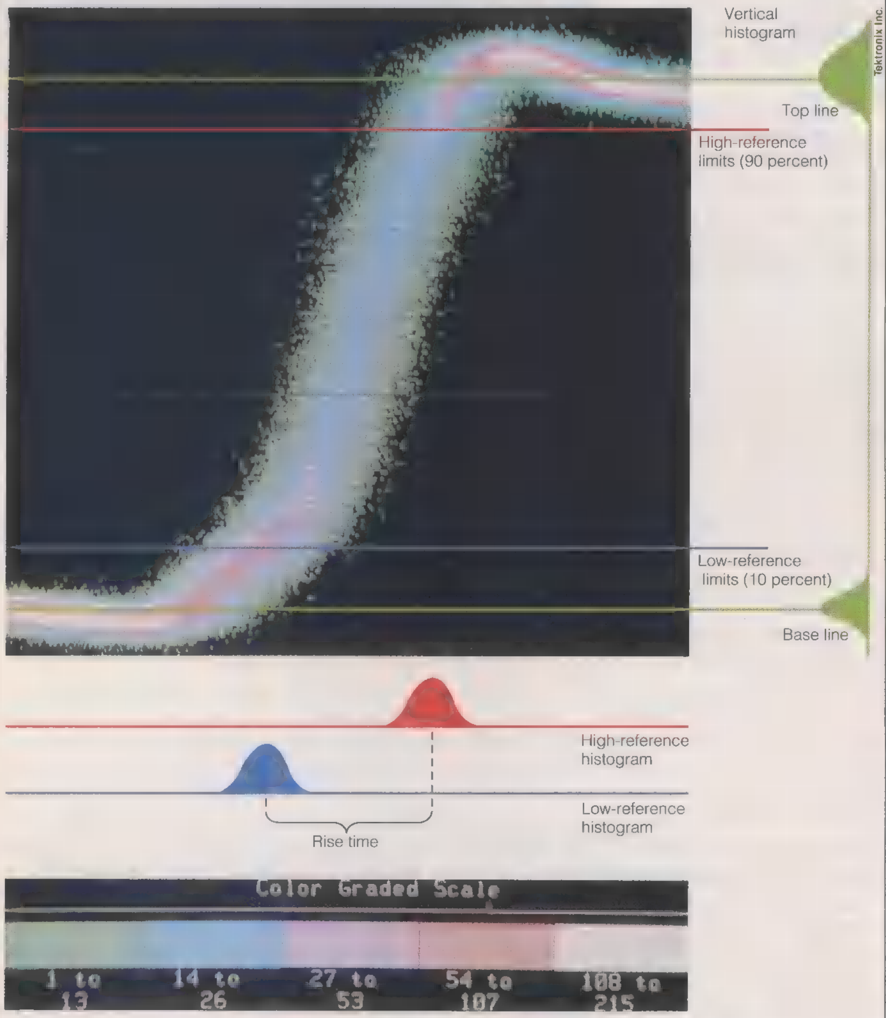
Statistical measurements, in contrast, are computed by examining the statistical concentration, or histogram, of samples in both the vertical and horizontal axes. A vertical histogram, in which the counts in each horizontal row of the database are summed [Fig. 2], is first used to determine top-line and base-line values—the two points on the vertical histogram with the greatest number of horizontal counts over the entire acquisition time. These values are then used to determine vertical levels at which horizontal histograms are calculated (that is, where ■ limited number of counts in each vertical column are summed).

Then one or more horizontal statistical concentrations or timing points are identified. These are generally referred to as low-reference (10 percent), mid-reference (50 percent), and high-reference (90 percent) crossings. From these vertical and horizontal statistical measurements, precise timing and voltage measurements can be made of, say, a signal's rise time.

In certain cases, statistical measurements and measurement statistics may yield the same result. However, here are some important differences:

- Measurement statistics are computed on measurements obtained using traditional measurement algorithms—they apply to waveforms that are single valued over time. They do not produce correct measurements on random data streams (those that are multivalued over time), such as are common in digital transmission systems, for instance.
- Measurement statistics typically have a much smaller sample size than statistical measurements. This may cause the mean value from measurement statistics to be unstable if the waveform has much noise or jitter.
- Since statistical measurements need many waveforms, it may take longer to get results.

NEW MEASUREMENTS. By working over the wealth of waveforms to be found in the



[2] To make a rise-time measurement using statistical measurement techniques, the top line and base line are determined using a vertical histogram. The top line and base line are used to establish the limits for the low- and high-reference histograms. The rise time is the difference in time between the peaks of the two histograms.

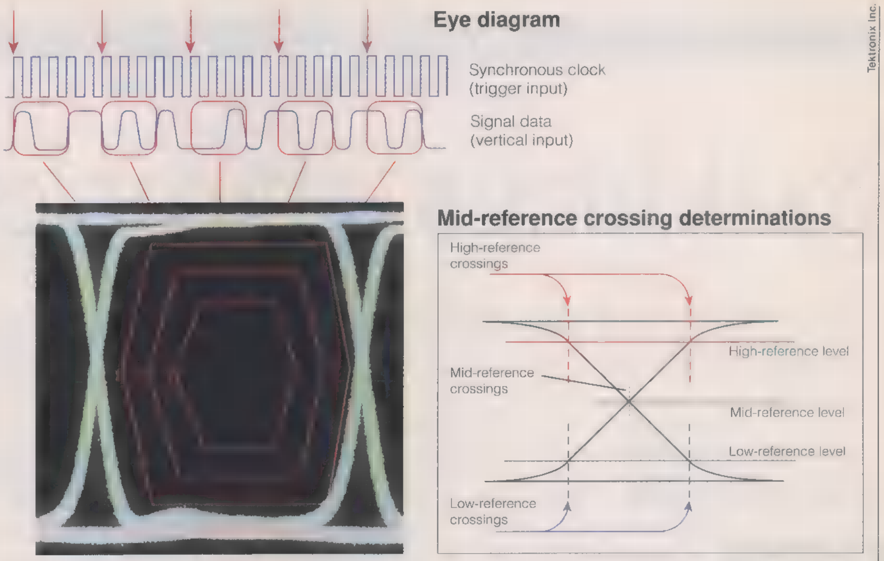
statistical database, statistical measurement algorithms make possible fully automatic, accurate, and repeatable measurements that were difficult or impossible to make till now. For example, traditional measurement algorithms produce highly unstable rise-time measurements in high-speed digital circuits with jitter. In modern DSOs, in an attempt to reduce the effects of jitter (and noise), signal averaging is commonly applied, but it has the effect of low-pass-filtering the signal, thereby degrading its rise time. The greater the jitter present, the more the signal's rise time (and hence bandwidth) is degraded. In contrast, statistical measurement algorithms extract accurate, repeatable measurements from signals with large amounts of jitter (and noise), not by averaging them, but by using the histographic data as the basis for the rise time measurement.

Jitter and noise, which have always been difficult to measure directly, are easier to measure with a statistical database because they are fundamentally statistical phenomena. Traditional automatic measurement algorithms do not lend themselves to making statistical measurements. Further, manual techniques, like cursor settings that are needed to initiate traditional automated measurements, are problematic; they are subject to differences in user setup and are hard to automate, since they rely on the user's visual capability to set up the measurement. The statistical measurement system can make the measurements directly and automatically, with virtually no guesswork or measurement setup required of the user.

Of particular concern to the telecommunications industry is making pulse parameter and timing measurements on random data streams, commonly referred to as eye diagrams [Fig. 3]. Making timing measurements on the acquired data from an eye diagram is virtually impossible with traditional techniques. The data acquired over many waveform acquisitions jumps at random between the eye's high and low states, which traditional measurement algorithms treat as actual signal transitions but which are merely random high and low bits. Thus a rise-time measurement on this type of signal usually yields the time between samples instead of the actual rise time of the signal.

Statistical measurement algorithms do much better. The following seven-step algorithm could be used to measure rise time on eye diagram data acquired into the statistical database, using techniques similar to those shown in Fig. 2.

1. Compute the top line and base line of the waveform by summing horizontal rows of database counts. Generally, there will be two large peaks in the sums—one at the top line and one at the base line, since these values occur most often.
2. From the top line and base line, compute the low-, mid-, and high-reference values (usually 10, 50, and 90 percent, respectively, for a 10–90 percent rise time).



[3] An eye diagram is formed by acquiring a random stream of serial digital data with an oscilloscope triggered by a synchronous clock (top). As the oscilloscope samples the random stream of high and low bits, it overlays the high and low samples from many acquisitions on the display. In the resulting diagram, which resembles an eye (bottom), the time of the mid-reference crossing does not lie between the first low- and high-reference crossings, as it does in a nonrandom signal, but succeeds these crossings.

3. Examine the counts in the database row corresponding to the low-reference level. For an eye diagram, there will be at least two peaks, corresponding to positive- and negative-going crossings through the low-reference level. Store the time of these crossings for later computation.
4. Repeat the process at the mid-reference level to find the mid-reference crossings. (Unlike the low-reference crossing on the eye diagram, there may be only one peak here.)
5. Repeat the process at the high-reference level to find the high-reference crossings. (As for the low-reference crossing, there will be at least two peaks here.)
6. Determine whether the waveform is an eye diagram by looking at the order of the low-, mid-, and high-reference crossings in time.

(An eye diagram is unique in that the first low- and high-reference crossings both precede the mid-reference crossing; this occurs because the eye diagram contains overlaid positive- and negative-going signal segments. In contrast, in the usual nonrandom pulse signal display, the mid-reference crossing always occurs between the low- and high-reference crossings.)

7. For eye diagrams, measure the time from the first low-reference crossing to the second high-reference crossing to find the rise time. This accounts for the overlaid positive- and negative-going crossings. For signals that are not eye diagrams, rise time is the time of the first low- to the first high-reference crossing.

Using similar techniques, other measurements—including width, phase, and propagation delay—can be computed from the statistical database. In addition, measurements are recomputed as new data is acquired into the database or when any measurement parameter changes. Since all the data is stored in the statistical database, changing measurement parameters or requesting new measurements does not require a new acquisition.

TO PROBE FURTHER. More detailed information on the color-graded technique and applications of the underlying statistical database can be found in a series of technical notes from Tektronix Inc., Beaverton, Ore. Included among them are *Color Grading and the Statistical Database*, note 47W-7806, 1990; *Using Histograms for Jitter and Noise Measurements*, note 47W-7804, 1990; *Mask Template Testing*, note 47W-7805, 1990; and *Statistical Measurements*, note 47W-7973, 1991.

An article by Rodney T. Schlater, "Waveform Graphics for a 1-GHz Digitizing Oscilloscope," *Hewlett-Packard Journal*, April 1986 (the company's headquarters are in Palo Alto, Calif.), discusses some of the benefits of variable- and infinite-persistence display techniques in DSOs.

N. Nishimoto et al., "New Method of Analyzing Eye Patterns and Its Application to High-Speed Optical Transmission Systems," *IEEE Journal of Lightwave Technology*, May 1988, provides information on the relationship between mask patterns and known bit-error rates.

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Switching to photonics

Voice, video, and data will eventually be switched by hardware that exploits the interplay of photons and electrons

Telecommunications in the future will rely on light as heavily in switching as it does today on light in transmission. The vast information-carrying capacity of optical fiber will be joined to the astounding connectivity of photonics.

Each new wave of switching hardware will have more photonics embedded in it. In 1995, the first specialized applications will be appearing. By 2000 there may not be purely photonic switching but there certainly will be abundant photonics; for example, photonic links will interconnect printed-circuit boards, multichip modules, and equipment frames. By 2010, optoelectronic switching fabrics could be bringing business community and residential customers alike a panoply of broadband services: video, high-definition television, and switched videotelephone conversations and conferences; fast data file transfers and information retrieval; data exchange for diskless workstations; and animated graphics, for example, all in addition to today's voice and data services.

A future photonic switching office for telecommunications will support more than 10 000 channels, each with a bandwidth greater than 150 Mb/s. The aggregate bit rate for the office's switching fabric will be greater than 1 million megabits per second (1 terabit per second). In contrast, today, channel bandwidths are 64 kb/s, and an electronic switching office handles an aggregate bit rate of less than 15 Gb/s.

ENGINEERING FOCUS. As of now, laboratories in industry and universities around the world are at work on a variety of photonic switching architectures and devices [see table, p. 45]. A few photonic switching devices have just come on the market, though they are still small arrays. In addition, some prototype hardware was demonstrated at the Telecom '91 conference in Geneva, Switzerland, last October. The focus now in many laboratories is on engineering—increasing capacity and performance while reducing size and cost. Still other concepts are in an early experimental stage.

H. Scott Hinton AT&T Bell Laboratories

The work is proceeding along two divergent paths. Guided-wave photonics is better understood and more highly developed. It capitalizes on temporal bandwidth: combining a large number of users into a single physical channel, either through time multiplexing or wavelength multiplexing, in structures like optical fibers and star and directional couplers. These structures are bandwidth transparent (support any bit rate).

The alternative, free-space photonics, exploits spatial bandwidth: serving many users in parallel through many separate channels in structures like lenses, mirrors, holograms, and arrays of optical logic gates or optoelectronic integrated circuits. Essentially, guided-wave photonic switching supports many users on a small number of physical channels, while free-space photonics supports a large number of users on a large number of lower-speed channels.

For future photonic switching offices, the aggregate bit rate will be an amazing 1 terabit per second

GUIDING WAVES. Probably the most highly developed version of guided-wave photonic switching is based on directional couplers. Indeed, these devices have been the mainstay of photonic switching for 15 years.

A directional coupler is like a switchtrack on a railway: it sends light signals straight through or diverts them to an adjacent channel. These devices can handle massive bit flows easily, but they are relatively slow in switching a signal from one path to another. They also are subject to cross talk and signal attenuation and cannot be integrated on a large scale. Nonetheless, they have an important application: as protection switches for fiber transmission links. If a failure occurs on a fiber link, a directional-coupler-based fabric can reroute its traffic all at once to an alternative link. The microsecond reconfiguration time required is trifling.

Ericsson Ab, Stockholm, Sweden, and AT&T Co., Berkeley Heights, N.J., now offer directional coupler switches for sale in eight-by-eight arrays (eight inputs switchable to eight outputs).

A basic directional coupler consists of two optical inputs, two optical outputs, and one or more electrical control input [Fig. 1]. Couplers are usually made of a crystal of lithium niobate into which a titanium channel is diffused to create a lightwave guide, although there has been some work on gallium arsenide and indium gallium arsenide phosphide material systems. A change in voltage on the device's electrodes alters the optical properties of the material, rerouting the channels from the bar or bypass state to the cross or exchange state (from straight through to criss-cross).

Up to a point, two-by-two directional couplers can be integrated in a single fabric. One factor limiting fabric size is the attenuation by the device of signals passing through it. But the signal loss can be reduced by special interconnection network topologies. For example, the dilated Benes rearrangeable network limits loss to a logarithmic (instead of a linear) increase with switch size—they keep loss low until the switches become very numerous.

A further limit on fabric size is cross talk. To minimize cross talk, special networks are used to ensure that no two inputs on a directional coupler are active simultaneously. Again, the dilated Benes scheme keeps cross talk low, although others, like the the Ofman and extended generalized shuffle networks, are good too.

Defining terms

Connectivity: effective number of connections to and from a device or other hardware.

Fabric: interconnection network hardware composed of switching nodes and links between them.

Fully connected: said of a switch in which any input channel can be connected to any output channel, provided another connection does not occupy part of the path.

Nonblocking: said of a switch in which any idle input channel can be connected to any idle output channel.

Packet-switched network: network that divides information into blocks, each containing address and control data.

Photonics: technologies based on interactions between electrons and photons.

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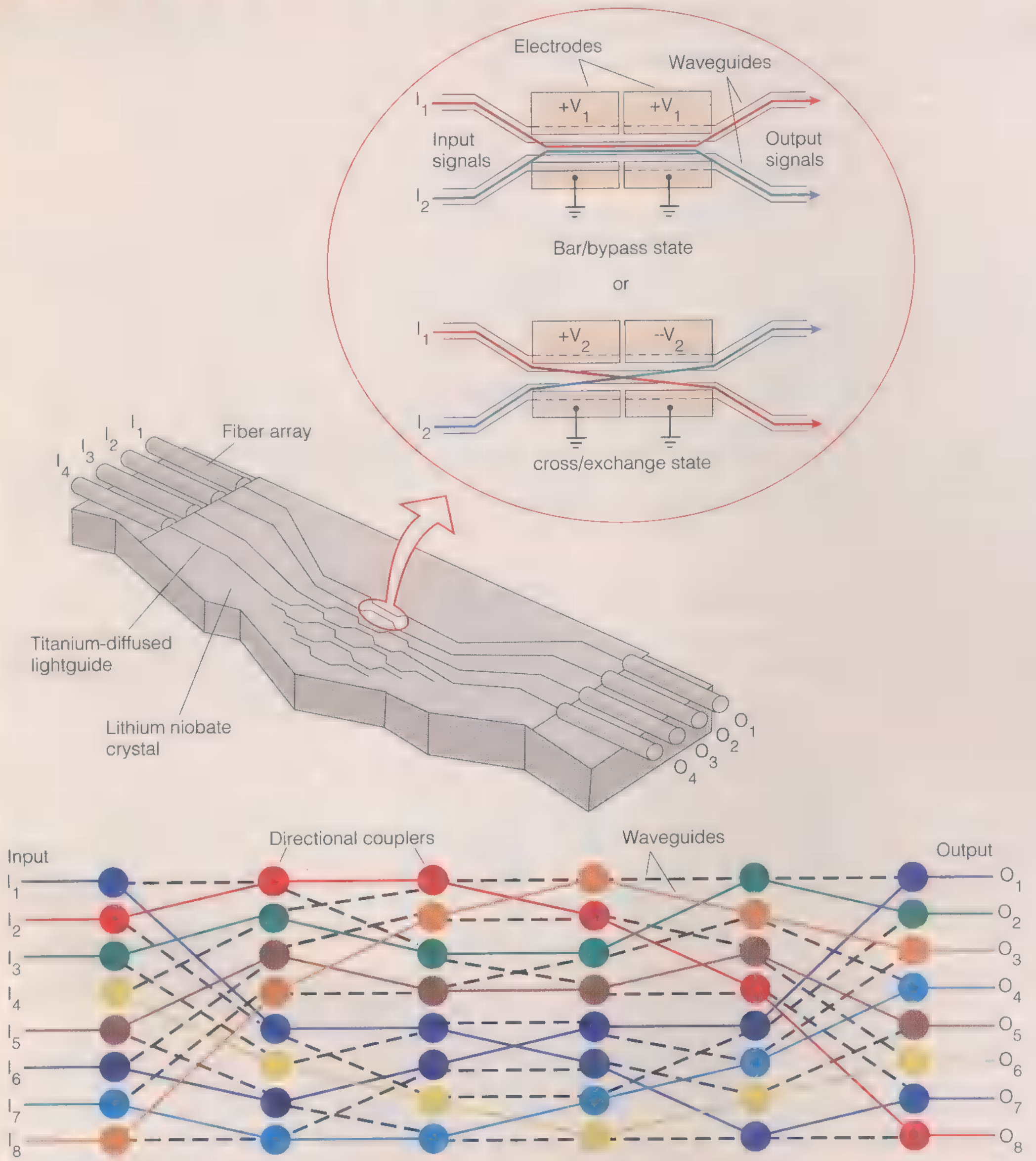
Anatomy of a directional coupler



[1] A directional coupler can route a light signal straight through (bar/bypass state) or switch it to an adjacent waveguide (cross/exchange state). Many such couplers can be connected together on a lithium niobate chip. When the couplers are joined in a pattern known as the dilated Benes network (an eight-input, eight-output version appears here), cross talk is minimized because any coupler can have only one of its inputs active at any instant. Color lines show one of many possible configurations of paths from inputs to outputs; dashed lines show unused paths that become active when the switch is reconfigured by altering the electrode voltages.

Yet other limits on integration are the great length of directional couplers in relation to their width and the large minimum bending radius of the diffused waveguides. All these constraints add up to a maximum integrated array size of 32 by 32. Larger switching fabrics have to be built up by interconnecting 32-by-32 arrays.

Another approach to guided-wave switching is time-division, rather than space-division, multiplexing. The division can be done by interchanging time slots or by using multiple-access devices like star couplers.

In time-slot interchangers, users are assigned slots on a single channel. Switching is done by a reconfigurable fabric that rearranges the temporal positions of the slots according to each's destination. The slots are then separated and sent onward. The connection between users is virtual.

In multiple-access switching, however, the connection between users is real and physical, albeit intermittent. For example, a star coupler network combines all its input channels and distributes them equally to all its outputs. Decoders on the output ports, instructed by a central controller, select the input they want to receive.

SLOT INTERCHANGE. Most proposed photonic time-slot interchangers (TSIs), when an input arrives in a given time slot, send it directly to the desired output time slot in a single step, over an optical-fiber delay line. The photonic interchanger based on directional couplers chooses a fiber whose length will delay the input slot just the right amount to fit it into the output slot. Work on this is being done at NEC Corp., Tokyo, and AT&T Bell Laboratories, Murray Hill, N.J..

The input is divided into time slots composed of many bits, with a little dead time between slots. That way, the coupler need not switch too often, and its low switching speed is not a handicap. Time slots for voice, data, and video users may be freely mixed. AT&T Bell Laboratories' Disco system demonstrated the principle in an eight-by-eight switching fabric.

Another kind of time-slot interchanger shifts the input slots through intermediate time-slot stages until they are in the desired output slot. With this scheme, the intermediate stages do not have to be fully connected or nonblocking, as they do in the single-stage interchanger. This time-division system is analogous to a multistage space-division network. One such system has been proposed by researchers at the University of Colorado, Boulder.

Time-division multiplexing by multiple-access fabrics may use a passive shared medium such as an optical-fiber ring. For input and output, the ring is accessed either by passive taps such as fiber couplers or by active taps such as directional couplers. In a synchronous ring, each user is assigned a unique time slot in which to read information from the ring. Other users can send information to a user by entering it into the destination user's time slot. Access to the time slots is arbitrated by a central controller. Asynchronous, distributed-control

schemes are another possibility.

Like time-division fabrics, wavelength division can rearrange input channels or share them through multiple access. A wavelength interchanger, for example, can switch a wavelength-multiplexed channel—one combining signals at different wavelengths. Since each user has a unique wavelength, a connection can be made between two users by converting a transmitter's wavelength to that of the appropriate receiver [Fig. 2].

In a wavelength interchanger recently proposed by NEC, the multiplexed input enters an optical splitter, where its power is divided equally among a group of internal channels. Each channel subjects the multiplexed input to coherent detection: the input is mixed with a monochromatic laser beam—tuned to a different wavelength for each channel—so that the information on the desired input signal is electrically extracted. This electrical information is used to modulate a fixed-wavelength output laser. The various output wavelengths are then multiplexed and sent on from the interchanger on a single optical-fiber channel.

A promising multiple-access wavelength interchanger is based on a star coupler, a device that combines all inputs and distributes them to all output channels. Each input has a unique wavelength. Each output channel has a tunable filter that a central controller tunes individually to match the wavelength of the input destined for it.

Several kinds of tunable filter are being pursued, including movable gratings, etalons (wavelength-selective interferometers), and coherent detectors. All devices have advantages and disadvantages. Movable gratings have good resolution but are slow. Etalons are fast but have less resolution. Coherent detectors offer both speed and high resolution, but are expensive to use because they need a tunable mixing laser.

TIME-SPACE-TIME. Multidivisional fabrics—those based on a combination of space-division and time-division multiplexing—promise huge throughput with rather little hardware. As yet, though, such systems are only in the concept stage. One proposal, from AT&T Bell Laboratories, calls for a 512-by-512 time-space-time photonic switch with an internal bit rate of 4.8 Gb/s. The 512 input lines, each at 150 Mb/s, are partitioned into 16 sections of 32 lines. Each section is time multiplexed into a single space channel, and all channels are fed to a 32-by-32 TSI, through a 16-by-16 space-division switch and then a 32-by-32 TSI, and finally demultiplexed into 512 channels, each at 150 Mb/s.

The challenge with time-space-time switching is timing. At 4.8 Gb/s, the bits will be only 208 picoseconds long, and, to prevent discontinuities in the output channels, they will have to be synchronized within 10 ps. The onus for the timing falls on the initial time-division multiplexer, unless an elastic store (one whose delay time can be varied) is placed at the input to the space-division switch. Control electronics will have to recognize 10-ps time differences.

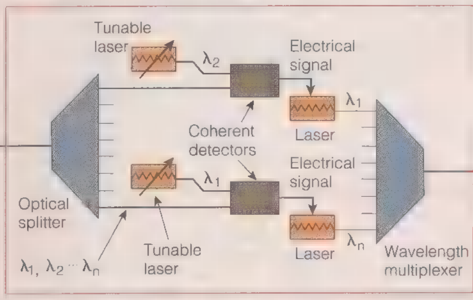
To minimize the timing burden, components will have to be packaged with extreme care. For example, if optical fibers between the initial time-division multiplexer and the space-division switch differ by only 1 cm, their bit arrival times will differ by all of 50 ps (for an index of refraction of 1.5).

RECONFIGURING FABRIC. A wavelength-division-based photonic packet switch is another kind of a multidimensional fabric. It is basically a multiple-access fabric that rapidly and continually reconfigures itself to time-share channels. In the Hypass system proposed by Bellcore, Livingston, N.J., packets of information entering the fabric are briefly stored in a first-in, first-out (FIFO) buffer, then used to modulate a laser tuned to the wavelength of the designated output port. A star coupler eventually transports all channels to receivers at the output ports.

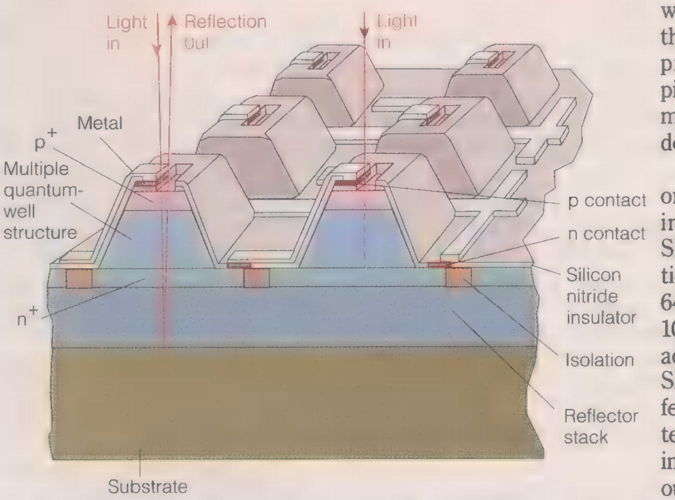
Control circuitry first checks the desired output port to see if it is busy, and, as soon as it is not, turns on and tunes the input laser to the wavelength of the receiver at the output port, finally commanding the FIFO buffer to send its stored information to the laser.

Free-space switching, although not as well-developed as guided-wave switching, is perhaps even more promising. Several laboratories are working on free-space systems based on two-dimensional optoelectronic ICs such as self-electro-optic-effect devices (SEEDs), double heterostructure optoelectronic switches, and vertical surface transmission electrophotonic device arrays.

QUANTUM WELLS. Of these devices, a symmetric SEED (S-SEED) is particularly useful. Its structure lends itself to fabrication in large arrays by batch-processing. An S-SEED is a pair of p-i-n diodes with multiple quantum wells in the intrinsic region [Fig. 3]. The diodes are electrically connected in series and reverse biased. One of the diodes is on (reflects light) while the other is off (absorbs light). Which diode is on is determined by the ratio of the powers of the light beams directed at each diode. The reflected differential light beams may then be processed through a lens or hologram to subsequent S-SEED arrays until they arrive at the required output channel.



[2] In wavelength interchanger, a multiwavelength input is divided among many coherent detectors. Heterodyned by a tunable laser, each coherent detector extracts an electrical modulation signal representing a discrete input wavelength and uses it to modulate a laser operating at a different wavelength. Any input wavelength can be switched to any output wavelength.



[3] Light entering a symmetric self-electro-optic-effect device (S-SEED) is either reflected or absorbed, depending on the ratio of power in the separate beams illuminating it and its neighbor. The multiple quantum-well structures are alternating layers of gallium arsenide and aluminum gallium arsenide, each layer about 10 nm thick.

The strength of S-SEEDs is that large arrays of small devices can be built. Using a gallium arsenide–aluminum gallium arsenide heterostructure for multiple quantum wells, workers at AT&T Bell Laboratories have fabricated, by molecular beam epitaxy, 128-by-256 arrays of S-SEED pairs. The weakness of the devices is that they require too much energy; at present they need about 1 picojoule to change state. Much more work also remains to be done on packaging.

Nevertheless, AT&T Bell Laboratories has built a 16-channel-input, 32-channel-output S-SEED-based fabric, an application-specific version of its 32-by-64 array. Operating at about only 100 kb/s, the fabric does not take advantage of the speed of S-SEEDs, but does demonstrate the feasibility of free-space optical interconnection and packaging. An incoming signal is routed to an output channel through six switching stages. At each stage, the signal is split in two and directed to an S-SEED pair. A control computer determines which of the pair accepts the signal. The S-SEED

Photonic switching technologies and players

Switching method	Photonic devices	Developers	Current status (devices and systems)	Advantages/disadvantages
Space division				
Guided-wave	Directional couplers	AT&T Co.; LM Ericsson, Stockholm, Sweden; Fujitsu Ltd., NEC Corp., and NTT Corp., Tokyo	4-by-4, 8-by-8 prototype devices available; research lab prototype systems	Bandwidth transparent/small-scale integration; difficult synchronization and control
	Digital switches	Ericsson		
	On-off shutters	Optivision Inc., Davis, Calif.	16-by-16 product available	
Free-space	SEED technology	AT&T; University College, London	Products available; system demonstrators	Digital devices/high switching energy; difficult optomechanical packaging technology
	Pnpn technology (DOES, VSTEP, EARS, LAOS)	AT&T; Colorado State University, Fort Collins; NEC; NTT; University of New Mexico, Albuquerque; University of Southern California, Los Angeles	Research prototype devices; research lab experimental systems	
	Smart pixels	AT&T; NEC; NTT; University College, London; University of Southern California	Simple research prototype devices; research lab experimental systems	Digital devices/difficult optomechanical packaging technology
Time division				
Time-slot interchange	Directional couplers, fiber delay lines	AT&T, NEC, University of Colorado, Boulder	Prototype devices available; research lab experimental systems	Bandwidth-transparent/small-scale integration; difficult synchronization and control
Multiple-access	Star couplers, tunable lasers, tunable receivers	AT&T; Princeton University, New Jersey		
Wavelength division				
Wavelength interchanger	Star couplers, tunable lasers, tunable receivers	NEC	Prototype devices available; research lab experimental systems	Bandwidth-transparent/small-scale integration; difficult synchronization and control
Multiple-access	Star couplers, tunable lasers, tunable receivers	AT&T; Bellcore, Livingston, N.J.; NEC; NTT; CSELT; Columbia University, New York City		
Multiple division				
Time-space-time	Directional couplers, fiber delay lines	AT&T	Prototype devices available; research lab experimental systems	Bandwidth-transparent/small-scale integration; difficult synchronization and control
Wavelength-space-wavelength	Star couplers, tunable lasers, tunable receivers	NEC		
Packet switching	Star couplers, tunable lasers, tunable receivers	AT&T, Bellcore		
	Smart pixels	AT&T; University College, London; University of Southern California	Research devices; research lab experimental systems	Digital devices/difficult optomechanical packaging technology

SEED = self-electro-optic-effect device.
DOES = double heterostructure optoelectronic switch.
VSTEP = vertical surface transmission electrophotonic.
EARS = exciton-absorptive reflection switch.
LAOS = light-amplifying optical switch.
CSELT = Centro Studi e Laboratori Telecomunicazioni SpA (Telecommunications Research and Study Center), Turin, Italy.

output from one stage becomes the input to the next stage.

Still in the future are fabrics composed of smart pixels—chips with optical detectors on their input channels, electronic logic in the middle, and either microlasers or modulators on their output channels. The signal-processing ability of electronics plus the communication ability of optics will yield complex, high-speed switching.

Finally, free-space optical interconnection can be used to link either multichip modules (MCMs) or printed-circuit boards. One proposal, from Bell Laboratories, for 2-D optoelectronic ICs envisions a 1024-by-1024 network in which each of three stages is an electronic MCM with more than 3000 optical inputs and outputs—an unprecedented challenge for package designers. The bit rate for each input/output channel would be greater than 150 Mb/s.

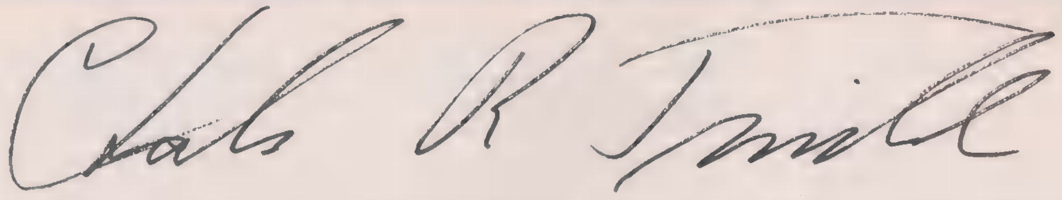
ABOUT THE AUTHOR. H. Scott Hinton [M] is head of the photonic switching department at AT&T Bell Laboratories, Naperville, Ill.

TO PROBE FURTHER. Author Hinton, with Joseph W. Goodman, John E. Midwinter, and Peter W. Smith, presented an IEEE Seminar via Satellite, "Photonic Switching in Communications and Computers," on Sept. 22, 1988. The three-hour program is available on videotape from the IEEE Service Center, Customer Service Department, 445 Hoes Lane, Piscataway, N.J. 08855-1331; 800-678-IEEE; outside the United States, 908-981-0060.

The Optical Society of America sponsors a topical meeting on photonic switching every two years, most recently March 6–8, 1991, in Salt Lake City, Utah. Proceedings are available from the society, 2010 Massachusetts Ave., N.W., Washington, D.C. 20036; 202-416-1980.

Photonic Switching, edited by H. Scott Hinton and John E. Midwinter, includes papers on switching network architectures as well as on devices and systems (IEEE Press, New York, 1990).

The *IEEE Journal on Selected Areas in Communications* published issues on photonic switching in August 1988 and 1990. ◆



This former HP engineer started his own company to exploit the newest free resource—the global positioning satellite system

In 1982 the U.S. Global Positioning Satellite program—a U.S. government plan to launch a constellation of satellites that would allow users worldwide to pinpoint their locations—was by no means a sure bet. Receiver technology was only in the research and development phase, and government budget slashing was already beginning to eat away at the project's funding. That year Palo Alto, Calif.-based Hewlett-Packard Co., which had had four engineers working on the technology for some four years, took its cards off the table.

Whereupon Charles R. Trimble decided to get into the game. A former HP engineer then leading a struggling start-up company, he put all his chips on the Global Positioning Satellite (GPS) program, and in spite of near disaster—the Challenger explosion put the GPS program on ice for three years—the gamble proved a winner.

And those winnings ballooned into a bonanza during the Persian Gulf War, when the U.S. military turned to Trimble Navigation Ltd. for some 10 000 portable GPS receivers. That kicked the expanding company into overdrive, and it is now growing at over 100 percent annually. From last year's revenues of US $63 million, analysts project 1991 revenues will be $145 million. The company currently has 750 employees, including some 200 engineers, an increase of 250 workers over 1990.

A quick tempo appeals to Trimble. Though a native Californian, he moves like a New Yorker late for a train, rushing from building to building in the Sunnyvale, Calif., industrial park that houses his company. In his career, too, he has always been a mover and shaker: in 14 years at HP, he was involved in four new ventures, leaving only when that company's intrapreneurism slowed down.

Tekla S. Perry Senior Editor

Trimble had intended to work as an engineer for only three months. In 1964, he had gained a master's in electrical engineering from the California Institute of Technology in Pasadena—which he picked in junior high school after hearing it was the hardest school to get into—and was planning to enter Harvard Business School in Cambridge, Mass., in the fall. Meanwhile, he took a summer job at HP.

"I viewed that as my only opportunity to understand the engineering world," Trimble told *IEEE Spectrum*. "So I put my heart and soul into it, working as many as 90 or 100 hours a week."

Before that summer, he had been strong on scientific theory, but had never even picked up a transistor. By Labor Day he was hooked on engineering, and called Harvard to withdraw.

Trimble blames that move on the man who hired him, Al Bagley, then head of HP's Frequency and Time Division, and his determination to keep Trimble out of Harvard's grasp.

Nor does Bagley deny the charge. When recruiting at Cal Tech that spring, he had heard about "this kid Trimble" from everyone—from professors to the clerks in the bookstore. The student was impressive in an interview, Bagley recalled, but did not want full-time employment. Bagley's bait was a challenge: could Trimble build a "computer of average transient"—a digital device that could analyze signals and spot repetitive signals amid noise? If he succeeded, Bagley promised that HP would market the creation as a special-purpose instrument.

The new graduate thought the project would take two years, but it took four, and his plans for business school faded. The HP 5480 Signal Averager bowed in the fall of 1968 and became primarily a biomedical research tool.

> 'When you get the reputation of a rebel, you are not going to move up in a conservative company'

If Bagley had had any doubts about his new hire's intrepidity, they dissipated one stormy day during a sailing race on San Francisco Bay. Safe onshore, Bagley saw masts breaking and on one small sailboat, a wildly swaying mast with Trimble perched atop.

"That is the sign of a gutsy guy," Bagley said, particularly in light of Trimble's congenital eye defect. Scar tissue on the retina deprives him of all central vision. He therefore cannot drive and must read through binoculars or by holding documents close to the periphery of his eyes.

INTRAPRENEURISM. When this "gutsy guy's" computer of average transient was completed and on the market in 1968, he asked for the chance to figure out a major new business area for HP's Frequency and Time Division. Bagley agreed, and Trimble targeted real-time dynamic testing of large-scale integrated (LSI) circuits. Assembling a team of 20 people, one of the largest groups in the laboratory, he began building a computer-controlled dynamic IC tester. Though static testers of LSI chips existed, no dynamic testers were then available for that level of circuit integration.

In 1971 the prototype was completed, but money looked tight for HP for 1972, and Trimble's project was canceled.

Then, undaunted, he started on another new project—focusing on single-shot time interval measurement and connectivity between electronic instruments and computers and calculators. One of his project managers became the instrumentation point man in the interfacing effort that led to the HP Interface Bus (HP-IB) and the IEEE 488 standard.

Trimble's last job at HP was as head of development for the Santa Clara–based bipolar LSI laboratory, which basically did contract engineering for other company divisions. Such a structure allowed for little discretionary work, and Trimble was interested in using the IC fabrication line to develop a new series of instruments capable of measuring time intervals as short as 50 picoseconds. So he persuaded corporate management to restructure the laboratory: in return for a fixed budget instead of total dependence on contract research, he would reduce staff and eliminate efforts in publishing and giving academic papers, which were taking up one-third of researchers' time.

Shaping the HP way to suit his goals was standard operating practice for Trimble, ac-

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Vital statistics

Name: Charles R. Trimble
Date of birth: Aug. 20, 1941
Place of birth: Berkeley, Calif.
Height: 175 cm
Weight: 77 kg
Family: wife, Marcia; daughter, Melinda, age 13
Education: B.S. in engineering (physics), 1963, and MSEE, 1964, California Institute of Technology
First job: selling avocados door to door
Oddest job: growing oat roots for biomedical research
Recent reading: *Tucker's Last Stand* by William Buckley
Favorite composers: Mozart, Strauss
Most respected role models: David Packard, Al Bagley, and Robert Cooper (former head of NASA's Goddard Space Flight Center)
Dislikes: brussels sprouts
Favorite movies: *Dances with Wolves*, *Soapdish*
A favorite expression: "Our assumptions are more confining than the laws of physics"
Leisure activities: sailing, cycling, chess
Pet peeve: when the person doing most of the talking has nothing to say
Management credo: "Trade autonomy for commitment"

cording to Jim Sorden, an HP colleague who is now vice president of product engineering at Trimble Navigation. "It was well known in HP that if you wanted to beat the system, talk to Charlie, and he would figure out the way," Sorden said.

When that project ended in 1978, Trimble looked around HP and realized that the environment had changed. The price for entrepreneurism by that time was working on projects that were 10 years from production. "HP had gone from a technology-driven to a marketing-driven to a resource-allocation company in my 14 years there," Trimble told *Spectrum*. It was time to go.

Colleague Sorden was not surprised. "Though Trimble did well at HP," he said, "when you get the reputation of a rebel, you are clearly not going to move up the ladder in a company that is becoming more and more conservative."

BOOTSTRAPPING. Trimble then turned his attention to an HP development project in Loran C navigation equipment that had been canceled. Loran C uses time differences between low-frequency radio signals from land-based transmitters to guide navigators primarily on the U.S. coastline and the Great Lakes. Trimble approached the project's division manager and, after several months of negotiation, purchased the Loran technology for $50 000, funds he obtained through refinancing an apartment building he had purchased earlier. He left HP with two engineers from the project, Thomas Coates and Daniel Babbage, and an administrator, Kit Mura-Smith, and set up shop as Trimble Navigation Inc. in November 1978.

Though he had always been a hard worker, Trimble was in for a few surprises when he took his entrepreneurial talents outside of the sheltered corporate environment. "I thought I knew what hard work and commitment was," he said. "But I was totally unprepared for the set of emotions and stresses involved in trying to bootstrap a business from zero."

On his own, survival was the No. 1 concern. Trimble said he was lucky to get through the early days: "I'm at a disadvantage in the $0–$2 million business level—I'm a strategist, not a street fighter."

By 1982 Trimble Navigation was selling about $1 million of Loran equipment annually. But growth in the Loran market was flat, so he began looking for a new business area to pursue. He found it again in the reject pile at HP.

The company had canceled a development program for navigation products that used the nascent Global Positioning System. At the time, plans called for GPS to be completed by 1987.

Trimble, enthralled with the idea of GPS as a free information utility ripe for commercial exploitation, bought the rights to an HP GPS breadboard in the summer of 1982. With the help of HP's original design team, doing after-hours consulting, he drafted a fundamental GPS block diagram, which he considers his best piece of technical work to date.

But Trimble lacked the time to work through several generations. He needed a product he could sell within 11 months, at which point, he calculated, the company would run out of money.

The product area he chose was an obscure one—time calibration of cesium clocks, using atomic clock signals from GPS satellites to calibrate the clocks at naval observatories—at best, a $1-million-a-year market.

> 'I was totally unprepared for the emotions and stresses involved in trying to bootstrap a business from zero'

Trimble knew that once the GPS constellation was complete, his $1.8 million company would have to have grown up, with revenues of at least $50–$100 million annually, because large competitors would then jump into the business. "We needed the resources to play in the end game," said chess player Trimble. The company required growth of 60 percent a year, and he consistently met and exceeded that.

In 1985 Trimble Navigation introduced GPS positioning for offshore oil surveying and developed a GPS navigation sensor for aviation (of use to pilots when the GPS constellation was complete).

Then in January 1986, with only seven GPS satellites in orbit, the Challenger blew up. GPS launches were put on hold until a new rocket booster could be developed for GPS satellites—a delay of three years.

"With the satellites up there, we could survey to 25 meters, which was good enough for offshore use," Trimble said. "If one satellite died, we could still survive. If two died, we would have been in deep, deep trouble." Meanwhile, the collapse of oil prices hurt the offshore survey marketplace.

So the company began looking for customers that were unconcerned about the number of satellites in the sky because they were confident of GPS's efficacy in the future. The prime candidate was the U.S. military, but the military had let an exclusive end-user receiver contract to Rockwell International Corp.-Collins Avionics and Communications Division through 1992, covering all the GPS applications it could think of.

The task for Trimble was to figure out applications Rockwell and the military had overlooked by assuming receiver equipment must cost a lot. He came up with a GPS brain for remotely piloted vehicles and personal position finders for the infantry, and soon created a small rugged finder that could be carried in the hand, in a pouch at the waist, or around the neck. The military took the bait, ordering 1000 Trimpacks at $4000 each, deliverable in May of 1990.

GULF BONANZA. When Saddam Hussein invaded Kuwait, the U.S. military began escalating its orders. Another 1000 units were purchased, then nearly 9000 more. Trimble went from a company shipping $5 million in products a month to one shipping $19 million a month just six months later—all the while hanging by its nails as components grew ever harder to obtain.

The only shadow on this success story is Trimble's dislike of being thought of as a military contractor. His is primarily a commercial and consumer products business, and he wants to keep any military manufacturing down to less than 20 percent.

Trimble cut his management teeth at HP and has, he said, managed the HP way ever since. He defines this managerial style as one of trading autonomy for commitment.

But autonomy does not mean hands off. On a summer's morning as observed by *Spectrum*, Trimble sprinted from meeting to meeting, carrying no documents and taking no notes, but seemingly up-to-speed in every area—from reviews of current chip designs in development, to government lobbying concerning export controls, to personnel requisitions, to new product proposals, to plans to push defects closer to zero. Mostly he listened, occasionally he asked questions, and often he stumped his engineers.

Modeling complex problems simply so they can be solved by himself or others—be the problems scientific, engineering, or economic—is one of Trimble's strongest talents. In fact, he said, detail bores him. Ralph Eschenbach, vice president of avionics and sensors at Trimble Navigation, thinks this aversion to detail relates to Trimble's eyesight, which identifies overall shapes better than fine detail. "He tends to force things into simplified models and doesn't get trapped with details," Eschenbach said.

Trimble himself attributes this skill to his family's practice of doing mental math games on long car drives, and to Cal Tech professor R. David Middlebrook, who insisted that students solve a problem on a single page.

These days, he said, his job is "to gather people around me who are far more talented than I am. It is their turn to generate the inventions."

TO PROBE FURTHER. Trimble Navigation Ltd. has published an explanatory guide to Global Positioning System (GPS) technology, called "GPS, a guide to the next utility" (1989). Copies are available from the Sunnyvale, Calif., company at 1-800-Trimble.

"Navstar: the all-purpose satellite" [*IEEE Spectrum*, May 1981, pp. 35–40] discusses the technology behind GPS and the original intentions for such a system. ◆

Hawaii's geothermal program

Though viewed as an environmentally benign way of generating electricity, the island's geothermal power plants come under fire

In a forest on the island of Hawaii, legal and regulatory activity has postponed the start-up of a small new power plant and imperilled the design and construction of several facilities like it.

The same old story? Hardly. The power plants at stake are not nuclear or coal- or even oil-fired, but geothermal, widely considered one of the more environmentally benign ways of generating electricity. In a further twist, the opposition is coming not only from the usual citizens' and environmental groups, but also from worshippers of a native god and, it has been alleged, growers of marijuana, a lucrative local crop.

The clash occurs just as geothermal power sources have finally proven commercially viable, experts say, adding that technological advances and industry trends in the United States and elsewhere seem to favor great expansion in its use. "Many utilities are seeing load growth in the range of 25–50 MW per year, and that's where geothermal can really compete," said Jim Combs, president of Geo Hills Associates, a Los Altos Hills, Calif., consulting firm.

Although under 1 percent of U.S. electricity is generated geothermally, the figure is 8 percent in California, where some 1400 MW are generated at a complex north of San Francisco known as The Geysers. Indeed, the state's Imperial Valley is to geothermal developers what Saudi Arabia was to oil prospectors earlier in the century. Geothermal energy has also been tapped extensively in New Zealand, Iceland, Italy, Mexico, the Soviet countries, Japan, and most notably the Philippines, where about 20 percent of electricity is geothermally derived.

The Hawaii installation is unusual in combining the two main types of geothermal facility: flash plants, in which turbines are driven directly by steam from the earth, with or without an admixture of hot water; and binary-cycle plants, in which heat from subterranean geothermal fluids is transferred to a second fluid, typically isobutane or isopentane, which drives the turbine. Binary-cycle plants began going into commercial service in the mid-1980s, and although they cost more to build, they have several advantages over flash plants.

BINARY BENEFITS. In a binary plant, the geothermal-heat cycle and the turbine cycle can be isolated from one another and the environment, minimizing the plant's impact on its surroundings. Also, they can be built to exploit geothermal resources of relatively low temperature—down to about 150 °C or so—opening up many more sites for possible use.

Even so, there are rather few places on earth where hot water is close enough to the surface to be exploited for power generation and these, more often than not, are far from population centers. The volcanically active island of Hawaii is one such place. "Technologically, it's a very good resource," said Richard Campbell, a project manager with the Pasadena, Calif., office of the Ben Holt Co., a leading builder of geothermal plants. Some estimates have predicted that at least 500 MW could be generated in the Kilauea east-rift zone, not far from the famous active volcano of the same name.

More than 90 percent of the energy used in the state of Hawaii is derived from oil, 93 percent of it from Alaska and the Asian-Pacific region and the rest also imported. Moreover, the island of Hawaii itself, which at present has only about 140 MW of capacity, faces supply shortages so severe that residents regularly wilt beneath rolling brownouts. "We've got about zero reserve margin on the Big Island," said William A. Bonnet, manager of the environmental department at Hawaiian Electric Co. in Honolulu.

Ironically, beneath the island lies a resource that Bonnet said was "one of the most promising geothermal sites on earth—and probably always will be." Exploitation of it seemed a good idea when first proposed in the early 1970s, partly in response to the Arab oil embargo. Now, however, some are not so sure.

DOUBLE WHAMMY. The most effective opposition to the project has been mounted by local residents and environmentalists with two main concerns: damage to the Wao Kele O Puna rain forest—one of a very few in the United States—in which some of the facilities would have to be built; and noise and gases, particularly hydrogen sulfide, emitted by the plant. (The gases, of natural origin, are dissolved in the superheated water and are released when it becomes steam.) Noise-abatement devices and scrubbers are typically used to restrict emissions.

Short- and long-term plans to develop the Big Island's resource were dealt two blows last June. At around 11 p.m. on the 12th, a well being drilled for the lone plant under construction, a 25-MW in-

Bishop Museum

A fiery Madame Pele, the native Hawaiian goddess whose wrath is said to mainfest itself in volcanic eruptions, was painted in 1890 by D. Howard Hitchcock.

Glenn Zorpette Senior Associate Editor

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stallation combining both flash- and binary-cycle turbines, underwent an "uncontrolled venting event," after the drill unexpectedly encountered a pocket of hot, high-pressure water some 1100 meters below ground.

Valves designed to prevent an uncontrolled release operated as expected, but the hexagonal "kelly," used to turn the drill, fell or was dropped into the circular valves, leaving gaps through which steam and hydrogen sulfide escaped. All told, it took about 31 hours to get control of the venting, according to Maurice A. Richard, vice president of Puna Geothermal Venture (PGV), the Hilo-based developer of the site.

COSTLY EXPERIENCE. The episode has proved costly to PGV. Six residences were temporarily evacuated and several dozen people living nearby, especially those with histories of allergies, reported various reactions. None of these afflictions, however, was verified by independent physicians or tied conclusively to the venting, according to the State Department of Health.

Nonetheless, in the wake of the accident, the state and county halted all geothermal activity, including drilling at the PGV site, and revised previous permits issued for drilling and construction. Tougher noise, gas-emissions, and safety regulations were imposed, which will "amount to millions of dollars in additional commitments," Richard said. So far, about US $100 million has been spent on the generating plant, which is about "98 percent" complete, according to Richard.

What remains to be done is to drill one or two more production wells, as well as an injection well (for the reinjection of condensate). PGV is now attempting to clear what Richard hopes will be the "last hurdle" before it can resume drilling: getting the county's approval of an evacuation plan, for use in the event of another accident like the one last June (the state has already approved the plan). Richard estimated that he could begin generating electricity as soon as a month after resuming drilling, but he had no idea when or if the county would approve the evacuation plan.

The second blow came only 12 days after the first. Although it is unlikely, at least in the immediate future, to affect the PGV venture, it could delay or even stave off large-scale development of the east-rift zone. On June 25, in response to a lawsuit filed seven months earlier by a national environmental organization, a Federal district court judge in Honolulu ruled that all geothermal research, development, and construction on the Big Island are part of an ongoing continuum of activities whose goal is the generation of 500 MW of geothermal electricity for transmission to Oahu (which uses 82 percent of the electricity generated in the state).

The judge's ruling has suspended Federal permits and support of any kind until an environmental impact statement (EIS) is filed for the 500-MW project. The PGV venture and a planned second 25-MW plant are largely unaffected by the ruling because they have already secured their permits, and their output will be used only on the Big Island.

Nonetheless, the latest ruling poses problems for developers and for the state because plans for generating and transmitting 500 MW from beneath the east-rift zone are still being formulated, and no one knows quite how a detailed EIS would be written. In February 1990, an international consortium led by Mission Energy Co., Irvine, Calif., was selected as the leading candidate to build a 500-MW geothermal complex, but the group has yet to sign a purchase-power agreement with Hawaiian Electric Co.

"We have not even begun to define exactly where the transmission lines would go," or whether electricity would be tapped off for the island of Maui, said Takeshi Yoshihara, deputy director of the Department of Business, Economic Development, and Tourism for the state of Hawaii. "The most we can do is a generic type of environmental-impact statement, and when projects become specific, they'll have specific impact statements." After the ruling, the anticipated startup date of a 500-MW facility quietly slipped to the late 1990s, from the mid-1990s time frame indicated in Hawaiian Electric's original request for proposals.

> A powerful coalition against geothermal power includes environmentalists, worshippers of a native god, and, possibly, marijuana growers

Nelson Ho, a vice president for the Hawaii section of the Sierra Club, the San Francisco–based environmental organization that filed the suit, said, "If you never look at the total package, you never get to see the true costs of the project, and what the true alternatives are. The cumulative implications of the project are never delineated for the public, nor debated in an open forum." His organization favors greater reliance on energy efficiency and conservation, with wind-, solar-, hydroelectric, and ethanol-derived energy making up any needed increments in capacity.

Last Oct. 23, the Sierra Club and 11 other organizations jointly filed a second lawsuit in state court. It is similar in many respects to the Federal one, but apparently seeks to link the second (planned) 25-MW plant to the larger-scale development, in an attempt to delay or prevent its construction. This plant, a project of the True/Mid-Pacific Co., worries environmentalists the more because it would be the first in the rain forest (the PGV facility is on cleared land formerly used for growing crops).

If a 500-MW complex were in fact built, estimates vary as to how much of it would be in the rain forest. Ho suspects that "all of it" would be; however, a recent study by Ogden Environmental & Energy Services Co. of Honolulu concluded that only about 200 hectares, part of it in the rain forest, would have to be cleared to make room for the power plants, with another 40 hectares required for transmission lines and a switchyard. The 240-hectare total is less than 3 percent of an area set aside for geothermal development, and an even smaller fraction of the total rain forest area in the eastern Big Island. Ho argues that the figures are misleading, however, and do not account for damage or harm to species and the delicate environment beyond the geothermal plants—for example, from plant emissions and the possible introduction of weeds or other alien plant and animal species.

POWERFUL COALITION. The Oct. 23 lawsuit, which has not yet come to trial, is also notable for its listing of the Pele Defense Fund as co-plaintiffs. This group filed a suit in Federal court several years ago alleging that any geothermal development would disturb Madame Pele, the native goddess of fire and volcanoes. The suit was ultimately defeated a year and a half ago when the U.S. Supreme Court refused to hear it, thereby upholding the Hawaii Supreme Court's rejection of the argument.

But the union of native peoples and environmentalists is proving a powerful one, not only in Hawaii but in the U.S. Pacific Northwest and in subarctic eastern Canada, where hydroelectric projects have been targeted by such alliances. "It's a potent combination that the industry, to date, has not taken seriously enough," said Ho, a former park ranger.

Another, less vocal ally in the Hawaii case is said to be growers of marijuana, who dread the discovery of their crops that activity in the forest could bring. "The biggest protest movement is being funded indirectly by the pot growers," said Combs, adding that at least two well-known opponents of geothermal development have been convicted of felony drug charges and other violations.

The Sierra Club's Ho concedes that "it's a known fact that the marijuana growers are here, but you never see them at any community functions, because they don't want to call attention to themselves, by questioning state policies or anything else."

TO PROBE FURTHER. Some technical challenges, notably that of linking the Big Island's geothermal output with demand centers on Oahu, are discussed in "Hawaii Deep Water Cable Program," a report prepared by the Hawaiian Electric Co. for the U.S. Department of Energy in 1990. ◆

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An experienced technical manager ■ sought to develop and administer the research programs for the Ohio Aerospace Institute. OAI ■ ■ consortium of nine universities, NASA Lewis Research Center, U.S. Air Force Wright Laboratory, and several dozen companies to perform collaborative research, graduate and continuing education, and technology transfer in an entrepreneurial environment. This is ■ senior position, reporting directly to the President. The individual will manage the collaborative research activity of OAI through its focus groups which ■ networks of university, industry, and government collaborators. There are presently focus groups in 13 different technology areas with more than 600 participants. Responsibilities will include management of the focus groups, organizing and administering cooperative research programs and proposals, and research program development.

The successful candidate will possess an earned doctorate in science or engineering, have ■ proven track record in research with demonstrated success in securing competitive funding and in research program development, possess strong oral and written communication skills, and ■ record of accomplishments ■ an effective team leader.

Resumes ■ nominations should be submitted by March 1, 1992 to:

Chair, Search Committee for
Director for Research
Ohio Aerospace Institute
2001 Aerospace Parkway
Brook Park, Ohio 44142

The Ohio Aerospace Institute is an Equal Opportunity Employer. All inquiries will be held in the strictest confidence.

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as Hewlett-Packard, Intel, Mentor, and Tektronix have major operation in the area and provide support for the electrical and computer engineering program. The Department h■■ modern facilities housed in a new building. Located in the Willamette Valley 80 miles south of Portland, OSU and the city of Corvallis offer ■ beautiful and unspoiled environment and many cultural activities. Applications must include ■ comprehensive resume, ■ list of three to five professional references, and a letter of interest. The letter must indicate clearly the position for which you are applying. Please send material to Chairman, ECE Search Committee, ECE Department, Oregon State University, Corvallis, OR 97331-3211. Review will begin March 1, 1992, and continue until the positions are filled. Oregon State University is an Affirmative Action/Equal Opportunity Employer and complies with Section 504 of the Rehabilitation Act of 1973. OSU has ■ policy of being responsive to the needs of dual career couples.

University of Minnesota, Minneapolis, Minnesota. The Department of Electrical Engineering invites applications and nominations for a tenure track or tenured position in Controls Systems. The duties of tenured and tenure track faculty include the establishment of ■ sponsored research program and teaching at both the undergraduate and graduate levels. The requirements of this position include an earned Doctorate in an appropriate discipline at the time of the appointment and outstanding academic and research records. Rank and salary will be commensurate with the qualifications and experience of the selected candidate. Applications and nominations should be sent with ■ resume containing the names of three references to: Professor Larry L. Kinney, Chairman, Faculty Recruiting Committee, Department of Electrical Engineering, University of Minnesota, 200 Union Street SE, Minneapolis, MN 55455. The last date for receiving applications will be April 1, 1992, for the position available September 16, 1992. The University of Minnesota is an equal opportunity educator and employer.

Full-Time Department Chairperson (12-month position, tenure-track): The Electronic and Electrical Engineering Department, California Polytechnic State University, San Luis Obispo invites applications for ■ full-time Chairperson with responsibilities commencing September 1, 1992. A Ph.D. in Electronic, Electrical, or Computer Engineering is required, together with prior administrative experience. Significant teaching experience at a primarily undergraduate teaching institution is also required. Professional experience in industry required, digital systems are preferred. The EL/EE Department, within the School of Engineering, has a full-time faculty of 25 and over 900 students. Undergraduate students major in one of two ABET-accredited B.S. degree programs, Electronic or Electrical Engineering, or a new B.S. degree program in Computer Engineering, jointly offered by the department and the Computer Science Department. Students are provided with extensive laboratory experience and ■ senior project, as well as ■ strong foundation in engineering sciences. M.S. candidates concentrate in the areas of Computer Engineering, Electrical Power Engineering, or Communications Engineering. The Department Chair serves as the chief administrative officer of the department and typically serves ■ term of three years. Although the Chair's responsibilities are primarily administrative, he/she is expected to teach one course per quarter and is considered a member of the instructional faculty. The teaching portion of this assignment is tenure-track. The Chair returns to full-time teaching at the expiration of his/her term(s). Academic rank and salary are commensurate with these qualifications and experience. Candidates for the position should send a resume, three letters of reference, and Ph.D. transcripts to the Chair of the Appointments Committee, EL/EE Department, Cal Poly, San Luis Obispo, CA 93407. Phone: (805) 756-2781. Fax: (805) 756-1458. e-mail: appt.cmty@photon.elee.calpoly.edu. The closing date for applications is April 1, 1992. Cal Poly is strongly committed to achieving excellence through cultural diversity. The university actively encourages applications and nominations of women, persons of color, and members of other underrepresented groups. Cal Poly is subject to all laws governing Affirmative Action and Equal Opportunity employment.

The University of Texas ■ Austin, Department of Electrical and Computer Engineering is accepting applications for tenure track assistant professor positions. Resumes will be considered in the following areas: 1) Software Engineering 2) Telecommunications Engineering, including microwave engineering; image and signal processing 3) Manufacturing Systems Engineering, and 4) Optical Interconnect Technology. Applicants should send resume and the names and addresses of at least three references to Dr. Mario J. Gonzalez, Chairman, Department of Electrical and Computer Engineering, The University of Texas at Austin, Austin, TX 78712-1084. The University of Texas at Austin is an Equal Opportunity/Affirmative Action Employer.

Electrical Engineering: Anticipated tenure-track faculty positions in the Electrical Engineering Department at West Virginia Institute of Technology effective August 15, 1992. All areas of specialization will be considered. Ph.D. in Electrical Engineering preferred; MSEE and significant experience considered; BSEE required. Responsibilities include developing and teaching undergraduate courses and labs and participation in scholarly activities. Commitment to teaching excellence, responsiveness to student needs, and good communication skills essential. Review of applications will begin April 1. Send letter of application, resume, three references with telephone numbers, and copies of transcripts to: Personnel Director, WVIT, Montgomery, WV 25136.

The PET Psychiatry Center of the University of Pennsylvania has ■ position at the Research Assistant Professor level for an individual to develop computerized image analysis methods for anatomic and functional neuroimaging. The candidate must have a PhD in physics, computer science or engineering and experience in PET/SPECT quantitation of anatomic and functional data within and across imaging modalities. C.V.'s, 3 letters of recommendation, and reprints should be sent to Joel Karp, PhD, Director, Physics and Instrumentation Group, Department of Radiology, Nuclear Medicine Section, Donner 110, University of Pennsylvania, 3400 Spruce Street, Philadelphia, PA 19104-4283. EOAAE.

Department of Electrical Engineering, North Carolina Agricultural and Technical State University, invites applications for tenure-track faculty positions at the Assistant and Associate professor rank in the areas of computer engineering, power systems and controls/power electronics, electronic and optical materials and devices. Applicants must have a Ph.D. in electrical or computer engineering with demonstrated teaching and research potential. Academic duties include teaching and developing both undergraduate and graduate courses, and initiating and conducting sponsored research. The Department offers BSEE and MSEE degrees with a Ph.D. degree planned for 1993. Currently, ■ cooperative Ph.D. degree is available through North Carolina State University. The 15 faculty members in the Department are actively involved in research in the areas of computer engineering, solid state electronics, communications, signal processing, photonics, and power systems. North Carolina AT&T State University is ■ constituent institution of the University of North Carolina system, and is a participating member of the Microelectronics Center of North Carolina (MCNC). Initial appointments are for 9 months at ■ rank and salary commensurate with qualifications. Interested applicants should send ■ resume and names of three references to: Dr. Ward J. Collis, Faculty Search Committee, Department of Electrical Engineering, North Carolina AT&T State University, Greensboro, NC 27411, no later than March 30, 1992. North Carolina AT&T State University is an affirmative action, equal opportunity employer.

North Carolina AT&T State University— Department of Electrical Engineering invites nominations and applications for the position of the Chairperson. Candidates must hold an earned PhD in electrical/computer engineering, and have professional achievement suitable for appointment at the rank of Associate or Full Professor. Leadership and management skills

Vascular Technologist

The Center for Neurologic Diseases at The University of Texas Southwestern Medical Center at Dallas is seeking a Vascular Technologist to perform transcranial Doppler, color flow and carotid studies. Applicants should have ■ high school diploma and must have completed ■ two-year recognized program in ultrasound or have a minimum of 2 years experience in the field of Vascular Technology. Must be registry eligible or registered with the American Registry of Diagnostic Medical Sonography. Clinical and research opportunities available. Please refer to #920076C.

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MEDICAL
DISCOVERIES
BEGIN
HERE

For further information, contact Cole Giller, M.D., Medical Director, or Angela Roseland, RN/RVT, Neurosonology Laboratory, Center for Neurologic Diseases, UT Southwestern, 5323 Harry Hines Blvd., Dallas, TX 75235-8897; or call 214-688-4800.

Equal Opportunity, Affirmative Action Employer.
We offer a non-smoking work environment.

THE UNIVERSITY OF TEXAS
Southwestern Medical Center
AT DALLAS

LIGO PROJECT

California Institute of Technology (Caltech)

Invites Applications for

Scientific Staff Positions

The Laser Interferometer Gravitational-Wave Observatory (LIGO) project is a joint effort by Caltech and MIT scientists to establish ■ gravitational-wave observatory, consisting of two facilities with laser interferometric detectors located far apart in the U.S. and operating in unison. Construction for LIGO will take about five years, and an FY '92 construction start has been authorized. The project is sponsored by the National Science Foundation.

1. The LIGO project has several new staff positions at Caltech for Ph.D. physicists who wish to participate in the R&D, design, construction and ultimately, operation of LIGO. While expertise related to optics, vibration isolation, control systems, electronics, and related fields is useful, the most important requirements of candidates are that they be broadly trained and experienced experimentalists who love experimental work, that they are willing to learn new experimental and analytical techniques, and that they share enthusiasm for building ■ first gravitational-wave observatory for studies in physics and astrophysics and for pioneering this new scientific discipline.
2. The LIGO project also is recruiting a senior physicist or engineer who will be in charge of the design of the detector data acquisition and control system. This position requires prior experience in the design, construction, and operation of large and complex data acquisition and control systems.

Materials in support of an application should be sent to **Prof. Rochus E. Vogt, Director, LIGO Project, Caltech 102–33, Pasadena, CA 91125.** These materials should include a curriculum vitae, list of publications, and the names, addresses, and telephone numbers of three or more references. Applicants are requested to ensure that three or more letters of recommendation be sent directly to the LIGO project.

Caltech is an Affirmative Action/Equal Opportunity Employer
Women/minorities are encouraged to apply

Director Research Institute

The University of Dayton invites applications and nominations for the position of Director, University of Dayton Research Institute. The Research Institute annually conducts approximately $40 million in sponsored research with a staff of 450 full-time personnel.

The University. The University of Dayton, founded in 1850 by the Society of Mary (The Marianists), is the largest independent university in the State of Ohio and the ninth largest Catholic university in the nation. The University of Dayton consists of four schools – Engineering, Law, Business, and Education – plus a College of Arts and Sciences. Total graduate and undergraduate enrollment is 11,000. The University's attractive campus is situated within ■ dynamic metropolitan area of more than 800,000 people and offers many cultural, recreational, and educational amenities.

The Research Institute. Established in 1956 as an integral part of the University, the Research Institute conducts both basic and applied interdisciplinary research primarily in engineering and the physical sciences. The full-time staff includes 300 professionals, augmented by 86 part-time professionals, 75 faculty, and 300 graduate and undergraduate students. The Institute, which ranks in the top ten of university DoD contractors, conducts more than 1000 projects annually, sponsored by government, business and industry.

The Position. The director of the Research Institute is responsible for the development and conduct of sponsored research programs in accordance with the University's teaching, research, and public service mission. This executive position provides leadership in policy development, short- and long-term planning, staffing and budgetary control, and the development and promotion of the University's technology transfer program. The director reports to the Vice President for Graduate Studies and Research.

Qualifications. Candidates for the position must have a distinguished record in research, proven management skills, demonstrated leadership, strong promotion and marketing abilities, and significant experience with grants and contracts. U.S. citizenship is required and an earned doctorate is preferred.

Applications and Nominations. Applications should include ■ complete resume and ■ letter summarizing the candidate's education, experience, and related qualifications. Please submit applications or nominations by March 1, 1992 to:

Dennis Stafford
Search Committee Chair
University of Dayton Research Institute
Dayton, Ohio 45469-0101.

The University of Dayton

The University of Dayton is an Equal Employment Opportunity, Affirmative Action Employer.

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Assistant Research Engineer to work on ■ newly established research program in the beam-plasma research area. A minimum of two years of experience with rf systems, linear accelerators, plasma sources, plasma diagnostic techniques, beam diagnostics and short pulse lasers is desirable. A Ph.D. degree in Physics or EE necessary. The position is for one or possibly two yers. UCLA is an affirmative action employer. Women and minorities are encouraged to aply. Send resume to Ms. Maria Guerrero, UCLA Electrical Engineering Dept. Engineering IV Bldg., Room 56-125B, Los Angeles, CA 90024-1594.

Boston University. The Department of Electrical, Computer and Systems Engineering at Boston University seeks applications for four anticipated faculty positions in the areas of electronic and photonic devices, computer and software systems, VLSI and neural networks, and data communications. All positions are for tenure track or tenured appointments starting in September 1992. An earned PhD in a relevant discipline is required. Faculty are expected to develop a program of funded research in their area of expertise. Boston University is located in the heart of the Boston academic community along the Charles River, with easy access to the outstanding scientific, cultural and tourist attractions of the city. The Department has 33 faculty and approximately 50 PhD, 250 MSc and 600 BSc majors. Opportunities exist for collaboration with other colleagues in the Boston area, as well as with the leading electronics and software companies in the area. Applicants should send their curriculum vita to Professor Thomas G. Kincaid, Chairman, Department of Electrical, Computer and Systems Engineering, Boston University College of Engineering, 44 Cummington Street, Boston, MA 02215. Boston University is an Equal Opportunity/Affirmative Action Employer.

Government/Industry Positions Open

Design Engineer to design new products (next generation of portable computers & computer with Chinese character recognition); develop new applications for existing products & diagnose network & hardware problems (testing & system troubleshooting). Work on such projects as INTEL 80386 (DX & SX) & 80486 SX laptop computers, Pen based Notebook computers with artificial intelligent features, portable workstations, etc., utilizing background in 16 bit or 32 bit microprocessor based digital system, PC memory mapping, AT Bus structures, & timing & loading. Requires M.S. in Electrical Engineering with emphasis on digital/microprocessor design ■■ evidenced by 5 courses associated with the subject. We are asking for 3yrs. direct exp. but in lieu of direct exp. willing to consider a candidate who has worked 3yrs. for a computer manufacture & whose duties included testing/troubleshooting computer systems (title or job classification & type of computer are not a factor). Also required is ■ graduate school project involving the actual design of a 16 bit or 32 bit microprocessor based computer system and ■ graduate school project in which the applicant used his/her knowledge of PC (specifically, PC memory mapping, AT Bus structures & timing & loading) to design computer hardware. Salary $38,000/yr, 40hrs/wk, 8am-5pm, no o.t., M-F. Must have proof of legal authority to work permanently in the U.S. Send resume to: Illinois Department of Employment Security, 401 South State Street-3 South, Chicago, IL 60605. Attn: Maxine Counts, Ref.#V-IL 4605-C. No Calls. An Employer Paid Ad. Must be fluent in Chinese.

Electrical Engineer. Conducts Research and develops activities concerned with electrical components equipment and systems for electrical machinery and controlled equipment. Assembles and tests electronic equipment and controls. May maintain and repair various electrical components and systems. Designs and develops electrical components, controls and related electrical systems. Forty (40) hours per week; $31,540.00 per year; 6:00 a.m. to 3:00 p.m.; Must have B.S. Degree in Electrical Engineering; 1½ years experience; Must have proof of legal authority to work permanently in the U.S. Send resumes to the Illinois Department of Employment Security, 401 S. State Street -3 South, Chicago, IL 60605, Attention: E. Reed; Ref. #V-IL-3869-I; No calls; 2 copies of your resume required; An employer-paid ad.

Manager of Engineering Operations. The Company is ■ manufacturer of medical and laboratory research instrument electronics. The Manager of Engineering Operations directs the development and engineering of current and new products related to magnetic resonance imaging and spectroscopy systems and EPR research instrumentation, including RF coils, gradient coils, loop gap resonators, antenna electronics and accessories. The Manager of Engineering Operations also provides technical support and direction, including possible invention, for the engineering design and production of MR imaging and spectroscopy cells. In these areas, the Manager of Engineering Operations is responsible for directing and overseeing new product research and development, staffing, budget, and customer support. The position requires ■ Ph.D. in Physics, and at least five years of experience as the manager or director of an engineering department of ■ manufacturer of magnetic resonance imaging equipment, and at least two years of experience with radio frequency electronics. The latter two requirements can be obtained concurrently. $80,000/yr., 40/hr. wk. Send resume to Wisconsin Job Service, 819 North Sixth Street, Milwaukee, WI 53203, ATTN: Bernice Kimbrough. Job Order #0556041.

ATTENTION SENIORS AND GRADUATES

JOIN THE PROFESSIONALS: WIN A SUMMER AT SPECTRUM MAGAZINE!

Make this summer your most exciting yet by joining the intellectually stimulating and professionally demanding world of technical journalism. Work alongside some of the best electrotechnical editors in the business as they produce their next award-winning issue.

Sound like an impossible dream? It won't be for the senior student or recent graduate who wins the contest to spend the summer of 1992 in the New York offices of IEEE *Spectrum*.

The winner will interview story sources, help research and write articles, develop art and graphic elements, solicit and edit technical pieces, and proofread. He or she may even have ■ byline on a published article by the end of the summer.

Do you enjoy writing as much as engineering? Have you ever thought of a career in technical journalism? If you answered "yes" to both questions, and if your major is electrical engineering, computer science, or an equivalent technical discipline and your grades are good, you qualify for this contest.

To enter, write to Executive Editor Edward A. Torrero, IEEE *Spectrum*, 345 E. 47th St., New York, N.Y. 10017, explaining why you should be selected. Include relevant materials, such as term papers, engineering reports, and college newspaper stories, that you think strengthen your case. All entries must be postmarked no later than March 18, 1992.

CONTROL SYSTEMS ENGINEER

The Trane Company, ■ world leader in air conditioning technology, has an immediate opening for a systems engineer in Electronic Controls Engineering.

The systems engineer defines and establishes the requirements and objectives of, and integrates the control functions of, HVAC systems and equipment. Responsibilities include the development, design, test, and verification of control strategies and algorithms leading to the implementation of state-of-the-art microcomputer-based controls. Mathematical dynamic system models, computer-based real time simulation, and date reduction/analysis software ■■ developed and utilized to accomplish these objectives. Experience using ACSL and MATLAB are ■ plus.

We require a BS or MS in EE or ME with an emphasis in controls and 2-5 years of related experience.

Qualified women, minorities, handicapped individuals, Vietnam era and disabled veterans are encouraged to apply.

We offer a competitive salary, a comprehensive benefits package and a modern technology center. We are located in La Crosse, Wisconsin, a beautiful medium size city on the scenic Mississippi River with an abundance of recreational and cultural activities. Qualified candidates should send resume including salary history to: **The Trane Company, Staff Employment Dept. 548, 3600 Pammel Creek Road, La Crosse, WI 54601. For consideration, resumes must be received by 4:30 p.m. on 2/21/92.**

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Senior Software Engineer for computer systems/software developer in Southwest Ohio. Conceptualize, design, develop, and support file transfer packages for Unisys A/V/B series and CMS machines and running under different message control systems (COMS, GEMCOS, CANDE, NDL, VCS, DCS, MCS SMCS and CMS) and different operating systems (MCP, MCP/AS, MCP/VS, and CMS) and linking to IBM compatible PC's. B-20 workstations, UNIX workstations and APPLE workstations. Conceptualize, design and develop high speed file transfer solutions running Unisys emulation packages with Poll/Select, BNA, TCP/IP and OSI complaint protocols. Provide programmatic interface to DMSII data extraction packages for Unisys A/V series machines. Provide training and support to Quality assurance, Documentation, Sales and technical support staff. Provide customization, installation and training support to customers. Job requires Bachelors Degree in Electrical Engineering or Computer Science and 4 years experience as Software Engineer/Systems Analyst. Three years experience on Unisys A/V/B Series and CMS mainframes must be in: (1) design and development of software applications using COBOL74 and WFL languages; (2) MCP and basic systems operations and utilities (including CANDE, COMS, GEMCOS, DUMPALL, KEYEDIO); (3) design and development of On-line and Transaction Based Routing applications, and; (4) design, development, and maintenance of DMSII databases and applications including DMUTILITY, DMINQUIRY, and DASDL. Must have at least one year's experience in design and development of inter-program communication schemes on Unisys mainframes. Must have at least six months experience in developing file transfer and DMSII data extraction applications on Unisys mainframes. Experience must also include at least three months developing software applications using ALGOL and developing COBOL applications on IBM compatible PC's. 40 hrs/wk; overtime as needed; 8:00 a.m.-5:00 p.m. Salary: $38,200.00/yr. Must have proof of legal authority to work permanently in United States. Send resume in duplicate (No Calls) to J. Davies, JO# 1230811, Ohio Bureau of Employment Services, P.O. Box 1618, Columbus, Ohio 43216.

Patent Law Opportunity—Testa, Hurwitz & Thibeault, a major Boston law firm with a history of servicing electronic, biotechnology and venture capital clients seeks electrical engineers that have a BSEE degree and an interest in patent law. The firm will train you to prepare and prosecute patent applications before the U.S. Patent Office and to serve as a technology specialist in our counseling of our high technology clients. This is an excellent position for an EE contemplating law school. Excellent package of compensation and benefits. For immediate consideration, please send resume in confidence to: Jennifer Silver, Recruiting Administrator, Testa, Hurwitz & Thibeault, Exchange Place, 53 State Street, Boston, MA 02109.

Systems Analyst; 40 hours per week; 8:00 a.m. to 5:00 p.m.; $38,000 per year. Customizing Business and Manufacturing Control System (BAMCS) by requirement analysis, design, development, testing and implementation of the system for steel industry and other manufacturing industries using CANDE, COMS, GEMCOS, DMSII, COBOL-74 and Algol. Analysis, design, development of systems in financial accounting and inventory control, using CANDE, COMS, GEMCOS, DMSII, File Management, Screenbuilder, COBOL-74. Required: M.S. in Design Engineering; a course in Design Methods and in Management Information Systems; six months experience using Business Manufacturing Control System (BAMCS) and six months experience in software development for the steel industry. Must have proof of legal authority to work permanently in the U.S. Send resumes to: Illinois Department of Employment Security, 401 S. State St., #3 South, Chicago, IL 60605, Attn: Gordon Doliber, Reference #V-IL 4585-G. 2 copies of your resume required. An Employer Paid Ad. No Calls.

(Continued on p. 53)

Government/Industry Positions Open

Microprocessor Engineer: A highly rewarding opportunity in hardware/software manufacturing system development is available for an electrical engineer or instrumentation physicist with outstanding academic credentials. Minimum requirements: masters degree, microprocessor applications, embedded control, professional publications, two years manufacturing experience. Experience in precision machine tooling also desirable. Doty Scientific is an attractive high-tech manufacturing and R&D company with an exceptional nine-year growth record. Competitive salary and benefits commensurate with abilities and experience. Send resume including copy of transcripts, and GRE or a SAT scores to: Judy Doty, Doty Scientific, Inc., 700 Clemson Rd., Columbia, SC 29223.

Engineer, Senior Research: Req. Ph.D. or the equiv. in EE with emphasis in image processing and 3 yrs. exp. in job offered or 3 yrs. exp. in digital signal processing software in video signals; data compression and related techniques, including transform coding, motion estimation, compensation techniques, DCT, and digital filtering; real-time implementations of signal processing routines; UNIX; C; video systems & t.v. broadcast standards. To design, develop, implement and test image and audio signal processing software and its hardware implementations for use in UNIX multi-media applications. Research compression technologies for use in future products. $80,000/yr. 40 hrs./wk. Job site/interview: Mountain View, CA. Clip ad and send with resume to Job #DN 8322, P.O. Box 9560, Sacramento, CA 95823-9560 no later than March 1, 1992. Upon hire must show immediate ability to work in the United States. EOE.

Design Engineer: Digital processing software design, employing Z transforms and Fourier, for the TMS320 family of processing products, used in the telecommunications industry. Requires design capability with analog and digital hardware which interfaces with digital signal processing software. Design involves use of the TMS320 assembly language programming. Perform digital filter design, (both IIR and FIR). Use numerical analysis concepts to improve signal quality. 8:00 a.m. to 4:30 p.m., 40 hours per week. $36,700.00 per year. Minimum requirements: M.S. in Electrical Engineering. Education must include at least one graduate course or 2 semesters of graduate research work in: a) digital signal processing, using TMS320 microprocessor, and TMS320 assembly language; and b) digital filter design (both IIR and FIR). Must have 1 year experience in the job offered. Must have proof of legal authority to work permanently in the U.S. Submit two copies of resume to: Illinois Department of Employment Security, 401 South State Street, 3 South, Chicago, Illinois 60605, Attention: Reference # V-IL 4273-G. NO CALLS. AN EMPLOYER PAID AD.

Engineer, Senior A. Resp. for generation & investigation of new concepts in electron devices for applic. in areas of microwave & medical equipment, imaging & signal processing: duties incl. improvement of materials & processing; device modeling, simulation & design; measurement of device perf. & eval. of design; definition, presentation & marketing to business units. Reqs. Ph.D. in Physics or E.E. with device physics conc. and 5 yrs. exp. with electron R&D. Also reqs. exp. in design, measurement & modeling over ■ broad range of electron devices & circuits, incl. unipolar/bipolar semiconductor devices; microwave devices & accelerators; radiation detectors & imaging devices; radiation damage; deep-level characterization in materials and devices; & electron noise processes. Salary: $1,483.16/week. Job & intrvw site: Palo Alto, CA. Send this ad & ■ resume to Job #TC11414 P.O. Box 9560, Sacramento, CA 95823-0560 not later than March 15, 1992. Must have legal right to work.

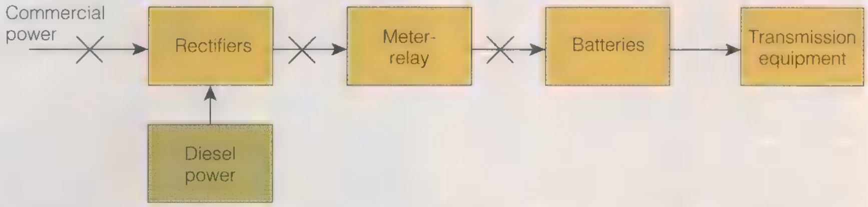
Government/Industry Position Wanted

Applied Mathematician (M.S. plus 1 year graduate work) retired from federal microwave measurements laboratory seeks temporary position (less than 6 months) in R & D project. Publications in guided wave systems. Prefer numerical math methods and coding in electromagnetic fields. Fortran or Rocky Mountain Basic. I have 486 PC. (303) 494-8405 or (904) 795-1639.

(Continued on p. 59)

Faults & failures

ΔV = 0.7 V = 85 000 irate travelers



When commercial power was cut, intentionally, so was diesel power, unintentionally, by a faulty meter-relay. Batteries alone then supplied telephone equipment.

A mere 0.7 V made the difference between a smoothly functioning telecommunications system and truly massive telephone outages and air transportation tie-ups throughout much of the northeastern United States last Sept. 17. According to a U.S. Federal Communications Commission report, a protective meter-relay, improperly set to trigger at 52.8 V instead of 53.5 V, overreacted to a voltage surge and cut off ac power to some transmission equipment at one of AT&T Co.'s most crucial facilities in New York City—the unit at 33 Thomas St. that serves Wall Street and three major airports.

The effects were far-reaching: 471 000 international calls and 4.5 million domestic calls were blocked from about 4.30 p.m. until service was fully restored after midnight. (The blockage could have been worse; the outage occurred as the business day was winding down and after many workers had left early to be home for the start of the Jewish holiday of Yom Kippur.) More serious were the effects on the air traffic control system run by the U.S. Federal Aviation Administration (FAA).

The FAA depends heavily on leased private lines that pass through the Thomas Street center. Thus, at 4.35 p.m. the FAA's regional air traffic control center at Ronkonkoma on eastern Long Island lost most of its links to radar sites, radio channels to aircraft, telephone lines, and computer links. The Ronkonkoma center handles all airline flights within a 330-km radius; controllers there suddenly could not communicate with pilots or other controllers.

The FAA stopped takeoffs from Newark, Kennedy, and Laguardia airports, where over 100 planes were in line for departure. Continentwide, flights to New York City were stopped.

Meanwhile, controllers scrambled to handle airborne traffic in the area. They diverted inbound planes or landed them, and they guided outbound ones carefully to adjacent control centers—all with limited, often improvised communications facilities.

When normal air traffic communications had been restored, Kennedy had 60 planes waiting and Newark had 70. Delays lasted into the next day, affecting 85 000 passengers and 1100 flights across the country.

How could a minor malfunction at Thomas Street cause such chaos? The answer involves faulty maintenance, failure to follow standard practices, poor judgment, reliance on vulnerable, collocated communications links, and bureaucratic intransigence.

The relay malfunctioned more than 6 hours before the communications outage. At 10.10 a.m., AT&T switched from commercial power to its standby diesel generators as part of a power-shedding agreement with Consolidated Edison Co., in anticipation of a hot, humid day. The switchover succeeded for 19 of the 20 power plants in the building. But the plant with the faulty meter-relay shut down the rectifiers feeding direct current to the batteries powering crucial transmission equipment. All day, the batteries silently supplied energy until they became exhausted, around 4.30 p.m., and the massive outage ensued.

In its investigation, AT&T found that the meter-relay apparently had been mis-set about three months before, when some modifications were made in the power plant. The meter-relay should have been tested at that time, but the installer did not follow the correct procedure.

When the meter-relay cut ac power to the rectifiers, the building's alarm system was immediately triggered—but no one heard the ringing bells or saw the flashing lights. The 20th floor at Thomas Street, where the inoperative power plant was located, is not normally staffed, and a walkthrough by maintenance personnel—standard procedure after a switch to standby power—did not occur. The regular maintenance staff was out of the building; its supervisor elected to go through with an off-site training session despite the power switchover, which had been done many times before without incident. No clear arrangements had been made for a substitute to do the walkthrough.

On the 14th floor, which is staffed around the clock, the alarm light did not work because its bulb was burned out. The audible alarm there did not work because its lead wire had been inadvertently cut during a recent equipment move. (A technician just arrived for the late shift noticed the alarm light on the 15th floor, but by then the batteries had to be completely disconnected before they could be recharged.)

At the time of the outage, AT&T had been installing a modern alarm system at Thomas Street. That system, now in place, does not rely on local surveillance exclusively; it also sets off remote alarms at a control center in Georgia. And the aging power system is being replaced. Immediately after the incident, AT&T began to reroute critical FAA communications lines to other offices so that not all pass through Thomas Street. If one office goes down, it will not take all communications with it. AT&T also will repudiate its load-shedding agreements, not just in New York but also in 28 other areas.

In November, AT&T put in service an emergency microwave link that had been under construction for the Ronkonkoma control center, *IEEE Spectrum* was told by Barry Boshnack, telecommunications spectrum engineering branch manager. "In addition, the FAA plans to operate its own microwave link early in 1992 as an alternative to the leased emergency link," Boshnack said. For further insurance, the FAA implemented a circuit diversity plan for the center. "Access lines now go through two central offices instead of one," Boshnack said, "so that if we do lose an office or lose network access through Thomas Street, we still have a path to get into the system."

For his part, New York City Mayor David N. Dinkins convened a panel of executives to find ways of restoring the city's telephone service quickly after massive outages. The panel's first recommendation was to institute carrier diversity: a carrier in trouble should call on any of 12 other carriers in the area to help with its traffic.

And the FAA at last got permission to go ahead with its Leased Interfacility National Airspace Communications System (Lincs), an advanced nationwide backup system that would take over, almost seamlessly, if a similar outage should happen. The U.S. General Services Administration previously had insisted that the FAA use the Government's general-purpose FTS-2000 system for backup, a demand the FAA had resisted, claiming that a dedicated system was vital.

COORDINATOR: George F. Watson
CONSULTANTS: John Devaney, Hi-Rel Laboratories Inc.; Robert Thomas, Rome Laboratory

EEs' tools & toys

Simulate an ant colony

Picture yourself at the head of a column of warrior ants, leading an invasion through the wilds of the backyard into a suburban house. A new software game, SimAnt, gives you a chance to grow an ant colony without getting your hands dirty. Then, by manipulating ant behavior, you can direct the "insects" in battles, invasions, and infestations.

The first step is to cultivate the ant colony, starting with one ant, a queen, and an egg. Tutorials based on the Pulitzer Prize-winning book by E.O. Wilson, *The Ants*, provide guidance. After the colony has matured, you may choose from several games. In the Quick Game, the object is to outbreed, outfeed, and outmaneuver the red ants. In the Full Game, you and your ants scheme to occupy the backyard and then infest the house, room by room, until the inhabitants run for the insecticide.

SimAnt software may be run on the IBM PC/Tandy with 640K bytes of memory under MS DOS or PC DOS 2.11 or higher. Macintosh PCs require 1 Mbyte for monochrome and 2 Mbytes for color (System 7: 2 Mbytes for monochrome and 2.5 Mbytes for color) with DOS 6.02 or higher. Amiga PCs require 1 Mbyte for low and 2 Mbytes for high resolution with DOS 1.2 or higher.

For the IBM PC/Tandy, the game software comes on four 5.25-inch disks and two 3.5-inch disks. For the Macintosh, two 3.5-inch disks suffice, and for the Amiga, three 3.5-inch disks. A user's manual with a science section is included in the package. SimAnt is a product of Maxis, is distributed by Broderbund Software, and sells for US $59.95. *Contact: Broderbund Software, 500 Redwood Blvd., Box 6121, Novato, Calif. 94948-6121; 415-382-4400; or* **circle 101.**

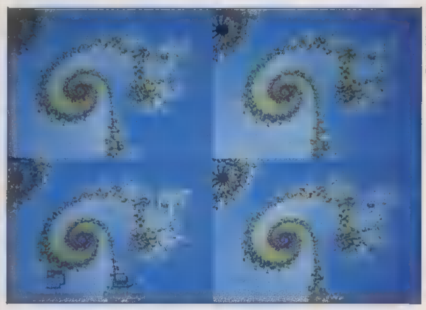
End background boredom

Does your Windows 3.0 wallpaper make you yawn? Now you can customize the Windows background with Fractals Wallpaper #1, a portfolio of 24 color patterns derived from fractals. These geometrical figures are generated by repeating adjacent, ever smaller shapes for an indefinitely greater number of times.

The most distinctive feature of fractals is self-similarity: when magnified, a small portion of the figure resembles some larger part, either exactly or very closely. Random, computer-generated fractal images resemble photographs of clouds, trees, landscapes.

Such patterns may be generated on personal computers with readily available programs, but then, they may take hours or even days to produce. In contrast, the Fractal Wallpaper patterns are produced on a high-speed parallel processor with a high-resolution color graphics system that can display over 32 000 colors. A process called diffusion dithering then converts them for display on a 16-color VGA system.

Pixel Visions has loaded some of these images into Windows 3.0 bit-map files for access through the Windows directory. Each pattern fills a quarter of the screen and four may be used to fill the screen.



Pixel Visions

This Fractal Wallpaper #1 pattern was generated on a parallel processor with a high-resolution color graphics system.

Fractal Wallpaper #1 costs $25 and is available for EGA or VGA on 5.25-inch disks in 16 and 256 colors. *Contact: Mike Tilley, Pixel Visions, Box 713, Glenn Dale, Md. 20769-0713; 301-474-1700; or* **circle 102.**

SOFTWARE

A CASE software source

Software-engineering tools and their suppliers become easier to locate and order with Toolfinder, a Personal Computer–based cross reference database on disc, and a 480-page sourcebook to the Computer Aided Software Engineering (CASE) industry.

The Toolfinder enables the user to find specific tools by using over 400 attributes in eight major categories: application types, development tasks, methods and notations, platforms, operating systems, databases, networks, and languages.

The Case Outlook Guide to Products and Services lists information on more than 850 tools from over 300 suppliers. Nine sections cover vendors and products, consultants, conferences, education, resources, institutions, standards, and workstations. Bibliography and glossary are appended. The workstation section includes a review of the leading computing platform features and prices, as well as a cost-per-seat analysis for state-of-the art CASE environments.

Three interpretive reports round out the volume. The CASE State-of-the-Industry Report describes technical trends in software design automation, changing market perceptions and expectations among suppliers, competitive strategies, and standards efforts. The CASE Outlook Software Tool Census shows the distribution of over 850 tools by the Toolfinder's eight categories, and includes an analysis of tool trends, areas of opportunity, and emerging tool niches. The CASE Outlook Software Tool Topology indicates in over 300 graphs how products from the industry's CASE suppliers address the software development cycle.

The sourcebook, Toolfinder disk, and additional reports together sell for $195. *Contact: CASE Consulting Group, 11830 Kerr Parkway, Suite 315, Lake Oswego, Ore. 97135; 503-245-6880; fax, 503-1245-6935; or* **circle 103.**

Demo of LabWindows 2.0

If you use C and Basic for data acquisition and instrument control, you might be interested in a demonstration at your desk of the software development program LabWindows 2.0. The demonstration disk, based on a version of the LabWindows 2.0 development system, is available free from National Instruments Corp., and has been translated into French, Italian, Japanese, and Spanish.

The disk includes illustrations of application programs in test and measurement, PC-based automatic test equipment (ATE), factory automation, process monitoring, process control, laboratory automation, and physiological monitoring.

LabWindows 2.0 combines standard industry products—hardware and software—into a single development system for data acquisition and instrument control. It enables the user to acquire data with and to control the general-purpose interface bus (GPIB), VXIbus, and RS-232 instruments as well as plug-in data acquisition boards. Analysis and data presentation capabilities of LabWindows 2.0 can be used to develop complete applications with either QuickBasic or C.

The program comes on 5.25- or 3.5-inch diskettes, and requires a PC AT, EISA, or Micro Channel computer running MS-DOS (version 3.0 or later), 2 Mbytes of memory, at least an 80286 processor, and an EGA or VGA display adapter. *Contact: National Instruments Corp., 6504 Bridge Point Parkway, Austin, Texas 78730-5039; 800-433-3488; fax, 512-794-8411; or* **circle 104.**

COORDINATOR: Dana Norvila
CONSULTANT: Paul A.T. Wolfgang, Boeing Helicopters

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Scanning The Institute

IEEE-USA position statements approved

The IEEE's United States Activities Board approved the following position statements at its last two meetings of 1991:

- IEEE-USA recommends that the Federal government develop programs to make more effective use of engineers in defense and nondefense industries, as well as Federal agencies, and that it support private sector strategies through legislative and financial means.
- Recognizing that high-resolution systems (HRS) development will affect many industries, IEEE-USA encourages all entities participating in standards development to evolve and adopt an open architecture for which flexible standards for HRS systems may be implemented.
- While backing physics research aimed at a timely demonstration of fusion as a viable, inexhaustible source of base load electric power, IEEE-USA also supports Federal funding levels adequate for studying the physics of a high-gain burning plasma.
- IEEE-USA points out the need for research in those areas that would contribute most both to understanding how low-intensity, low-frequency electric and magnetic fields interact with living matter, and to defining risk assessment objectives.
- The Federal Communications Commission must continue to be guided by public interest, not auction, in making spectrum allocations, though consideration should be given to using auctioning in the licensing process and management. IEEE-USA believes that these suggestions will further enhance the beneficial aspects of the license auction process and help clarify where auctioning is appropriate.

Copies of the position statements are available from the IEEE-USA office, 1828 L St., N.W., Suite 1202, Washington, D.C. 20036.

Eurocon 92 alert

Scheduled to be held in Zurich, Switzerland, May 18–21, Eurocon 92 is shaping up as a major event for Region 8 (Europe, including the former Soviet Union, Greenland, Iceland, and the Middle Eastern countries west of Afghanistan and Pakistan) and the IEEE Switzerland Section. Featuring talks by high-ranking leaders from the Commission of the European Community, industry, and academia on such topics as R&D in information and electrical technologies, as well as workshops on the role of Europe in a worldwide market, the meeting is expected to attract about 600 attendees. Contact the Secretariat Eurocon 92, TIK ETZ G 84 ETH-Zentrum, CH-8092, Zurich; (41+1) 254 7022; fax, (41+1) 251 2504.

New edition of employment guide

The third edition of a comprehensive two-volume employment guide, geared to the needs of engineers and scientists, has been introduced by IEEE-USA. The first volume of an *Employment Guide for Engineers and Scientists* is a manual for job hunters. The second volume incorporates an extensive directory of employers of engineers and scientists. Edited by Richard J. Backe, the guide is sold through the IEEE Service Center at US $14.95 for members and $19.95 for nonmembers, plus tax and shipping. Orders can be placed by calling 1-800-678-IEEE and requesting IEEE Catalog No. UH0186-7. IEEE-USA provides complimentary copies of the guide to unemployed U.S. members who are not students. Written requests that include member number should be mailed to IEEE-USA, 1828 L St., N.W., Suite 1202, Washington, D.C. 20036.

Coming in Spectrum

Open digital video. As digital video impinges ever more strongly on television, computer, and industrial applications, the standardization of its elements becomes urgent.

Designing FPGAs. To cope with the ingenious architectures of field-programmable gate arrays (FPGAs), ideas from gate-array and standard-cell design software have been mated with synthesis and optimization routines used for programmable logic devices.

After the flood. A broken water pipe or, worse yet, a fire need not reduce electronic equipment to scrap—in the hands of a professional disaster recovery company, the cost of restoring dirtied or damaged equipment is well below the cost of replacing it.

Curriculum reform. U.S. colleges are teaching electrical and computer engineering earlier, seeking to develop true (non-rote) understanding, and encouraging long-term design projects.

Finnish high-flier. Finland's Nokia Corp. is now Europe's third largest maker of TV sets and a rising star in mobile phones and telecommunications. But it must combat its out-of-the-way location and the recession.

Commerce and competition. The Commerce Department's Undersecretary for Technology Robert M. White tells how the Government is working with industry and academia to improve U.S. competitiveness.

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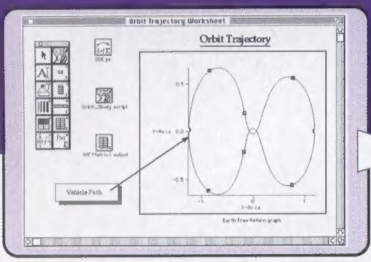

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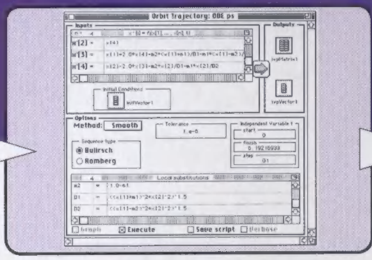

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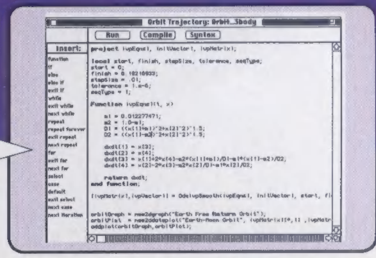

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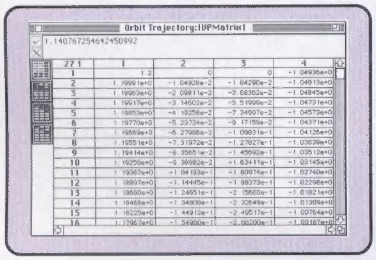

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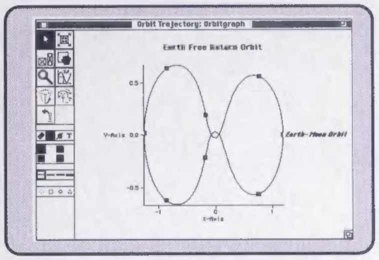

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